eRHIC Magnet Design Report 2012

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May 17th, 2013

This report details several designs developed for the eRHIC magnet. The `.cond` files for each of the designs and the `.comi` "Commands In" file are included at the end of this summary in Appendix. All plots generated in OPERA were done using the millimeter-Tesla "set-units" file.

Table of Contents

Introduction....3
Multiple Ring Solenoid (MRS)....4
Simple Solenoid (SS) & Multiple Ring Solenoid (MRS) Analysis....10
Dipole-Solenoid (DS) & Dipole-Wrapped Solenoid (DWS) Analysis....14
Coaxial Ring System (CoRiS) Analysis....22
Strobili Solenoid (StrobS) Analysis....27
Conclusion....30
Appendix....A1

Introduction

The realization of an electron-ion collider (EIC) is crucial to a detailed understanding the nature of QCD. One proposed EIC is eRHIC. The electron Relativistic Heavy Ion Collider (eRHIC) would be a major upgrade to the Relativistic Heavy Ion Collider at Brookhaven National Laboratory. eRHIC would enable collisions of protons and heavy ions on electrons with energies up to 20-30 GeV, enabling precise probing of the structure of matter. As a part of the eRHIC development process, a strong central detector magnet design is necessary for modeling the physics that will be measurable at eRHIC.

Our goal is to design a magnet that provides strong radial field in order to sufficiently bend particles with energies up to 10s of GeV and pseudorapidity up to approximately -5 so that their momentum can be determined with precision. This report provides a summary of the magnet design process for the eRHIC detector to date, including images, magnetic field plots, and particle trajectory simulations. All of the models experimented with are included herein to demonstrate the variety of designs investigated in order to develop the ideal magnet for the eRHIC. In addition, some of these novel designs may be of aid to other particle physics experiments.

Throughout the design process, we have been careful to avoid the dangers of high surface magnetic field. Although ample cooling of superconducting magnetic components may prevent quenches, we are wary of magnetic field strengths exceeding 6 T on the surfaces of any superconducting magnets. Beyond quenching fears, this practice also lends itself to overall cost concerns: the construction and operation of the magnet will be easier and cheaper if we utilize a lower and more uniform magnetic field.

Despite our best efforts at creatively thinking about how to maximize our momentum resolution, we haven't yet gravitated away from a basic solenoid design. One of our designs has incorporated dipoles, although this was purely to see the benefit of having a field perpendicular to the beam axis. In reality this kind of field would all but destroy the beam's progression around the ring as well as generate high levels of synchrotron radiation. Of all the designs experimented with, the MRS-B1 is the best candidate as of yet.

The remainder of this paper is structured around sections labeled for the magnet that is analyzed within. The designs are listed in the order in which they were designed and tested chronologically, with the newest magnet designs appearing towards the end of the report. Each section contains: an image of the magnet with color-coded segments, a small text-box with magnetic field values and dimensions, tables of the current densities in each magnet section, simulated particle trajectories, color-coded plots of the magnetic field modulus (in Tesla) with a line plot of the magnetic field modulus along the z-axis and a color-coded radial magnet field map (in Tesla).

Multiple Ring Solenoid- The MRS is an attempt to increase radial field through the use of several co-axial solenoids, each with increasing current densities (Fig. 1).

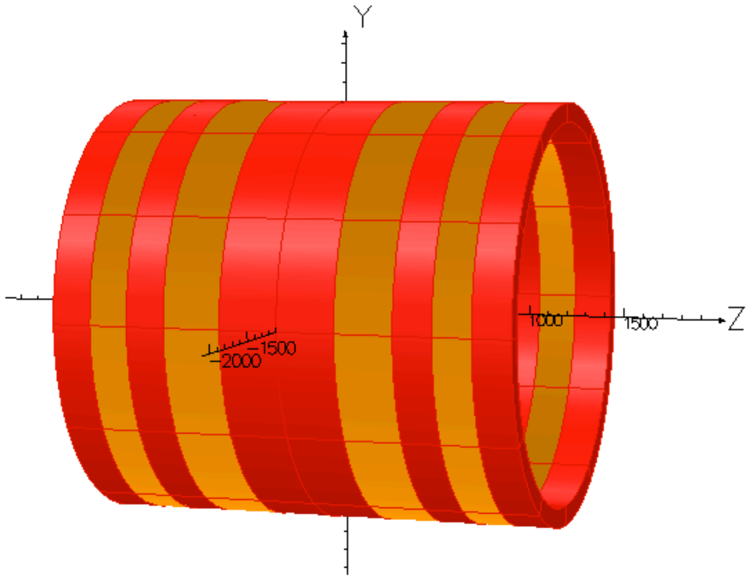


Fig. 1 – The MRS design is comprised of five solenoid pairs. The inner pair (red colored, along y-axis) is labeled as P1, with the last pair, P5, at z=± 1200 mm.

Total Length – 2.4 m
Inner Radius – 1.0 m
Outer Radius – 1.1 m

Central B field:
MRS-A - 3.001 T
MRS-B – 2.224 T
MRS-B1 -3.001 T
Peak Radial B:
MRS-A - 2.646 T
MRS-B – 5.546 T
MRS-B1 - 5.173 T

The overall length of the MRS design is 2.4 m with an inner radius of 1.0 m and an outer radius of 1.1 m (Fig. 1). The current densities are lowest in solenoid pair 1 (P1) and greatest in pair 5 (P5) (Tables 1A, 1B and 1C). The MRS-A solenoid setup yields a peak central magnetic field (x=0, y=0, z = 0) of 3.0 T and a peak radial magnetic field of 2.6 T (Fig. 1A & 1D).

Table 1A – Current Densities of Solenoid Pairs for MRS-A Design

Solenoid Pair	Current Density
P1	30.1 A/mm^2
P2	32.0 A/mm^2
P3	33.0 A/mm^2
P4	33.0 A/mm^2
P5	34.0 A/mm^2

The MRS-B solenoid setup yields a peak central magnetic field of 2.1 T and a peak radial magnetic field of 5.1 T (Fig. 1B & 1D).

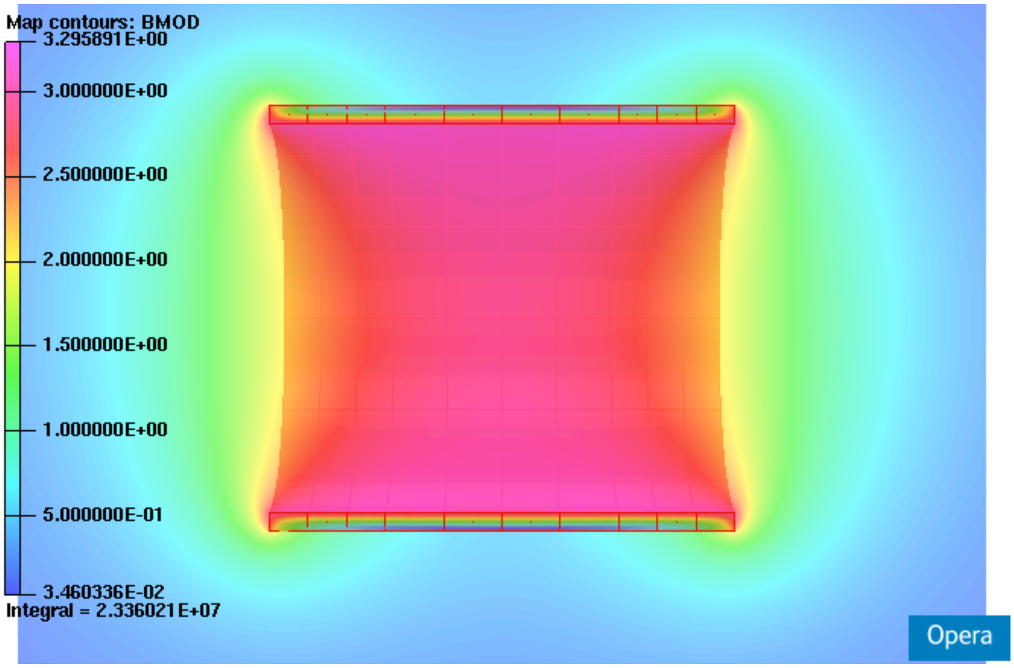
Table 1B – Current Densities of Solenoid Pairs for MRS-B Design

Solenoid Pair	Current Density
P1	6.25 A/mm^2
P2	12.50 A/mm^2
P3	25.00 A/mm^2
P4	50.00 A/mm^2
P5	90.00 A/mm^2

The MRS-B solenoid was designed around the maximum field allowed within the surface of a conductor, 6 T. This maximal current was determined within pair P5 to maximize the radial field and optimize the integral of the transverse field. The remaining solenoid currents were then made lower in the hopes of creating a gradient between the magnetic fields of each solenoid. This scheme gave a central magnetic field modulus that is smaller than in the other magnet designs, which gives less particle bending (Table 2A). This prompted the MRS-B1 design, which retained the central magnetic field modulus of ~3 T but also incorporated a gradient between each solenoid's field. The MRS-B1 solenoid setup has a peak central magnetic field of 3.0 T and a peak radial magnetic field of 5.2 T (Fig. 1C & 1D).

Table 1C – Current Densities of Solenoid Pairs for MRS-B1 Design

Solenoid Pair	Current Density
P1	12.08 A/mm^2
P2	30.00 A/mm^2
P3	40.00 A/mm^2
P4	50.00 A/mm^2
P5	85.00 A/mm^2



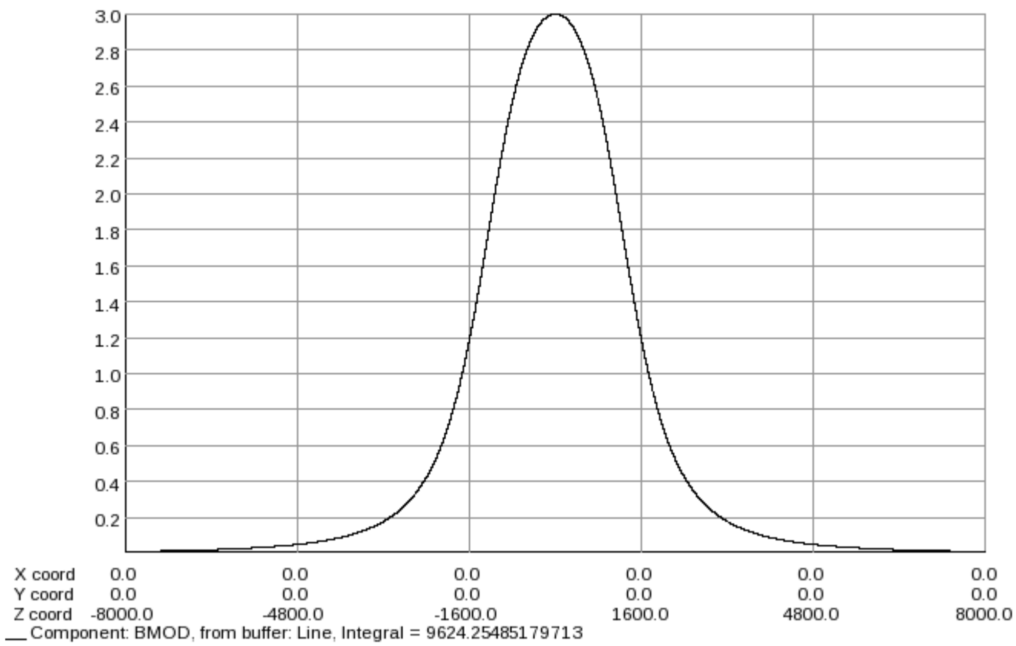


Fig. 1A – Magnetic field modulus mapping for the MRS-A. The central field strength (x=0, y=0, z = 0) is 3.001 T. The top diagram shows magnetic field strength with a color scale in units of Tesla on the y-z plane. The red box outlines show the boundaries of the magnet. The bottom diagram shows the magnetic field modulus in Tesla along the z-axis from z=±8000 mm. The magnet spans z=± 1200 mm. The plots were constructed with 600 x 600 resolution in the OPERA Post-Processor.

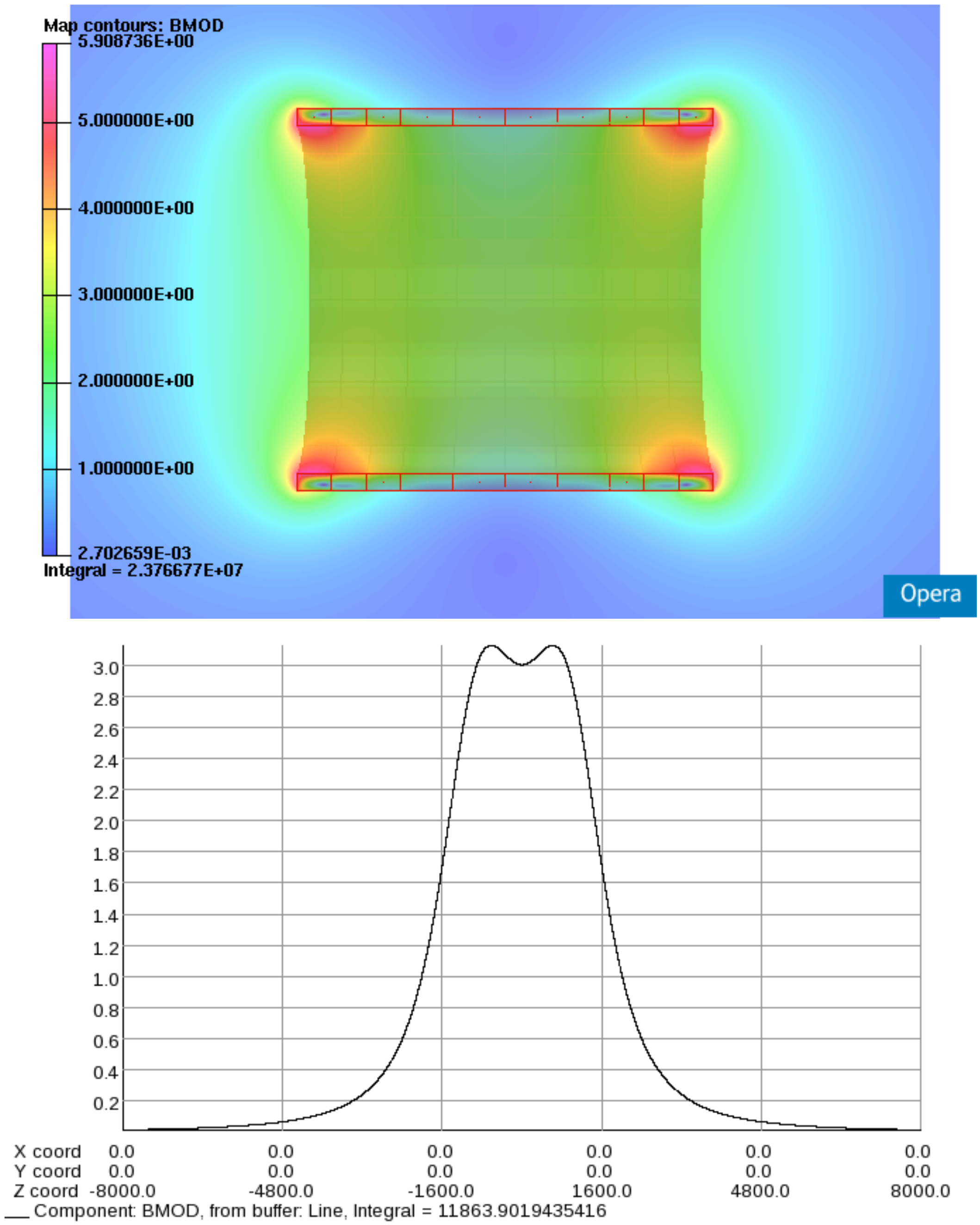


Fig. 1B – Magnetic field modulus mapping for the MRS-B. The central field strength (x=0, y=0, z = 0) is 2.145 T. The top diagram shows magnetic field strength with a color scale in units of Tesla on the y-z plane. The red box outlines show the boundaries of the magnet. The bottom diagram shows the magnetic field modulus in Tesla along the z-axis from z=±8000 mm. The magnet spans z=± 1200 mm. The plots were constructed with 600 x 600 resolution in the OPERA Post-Processor.

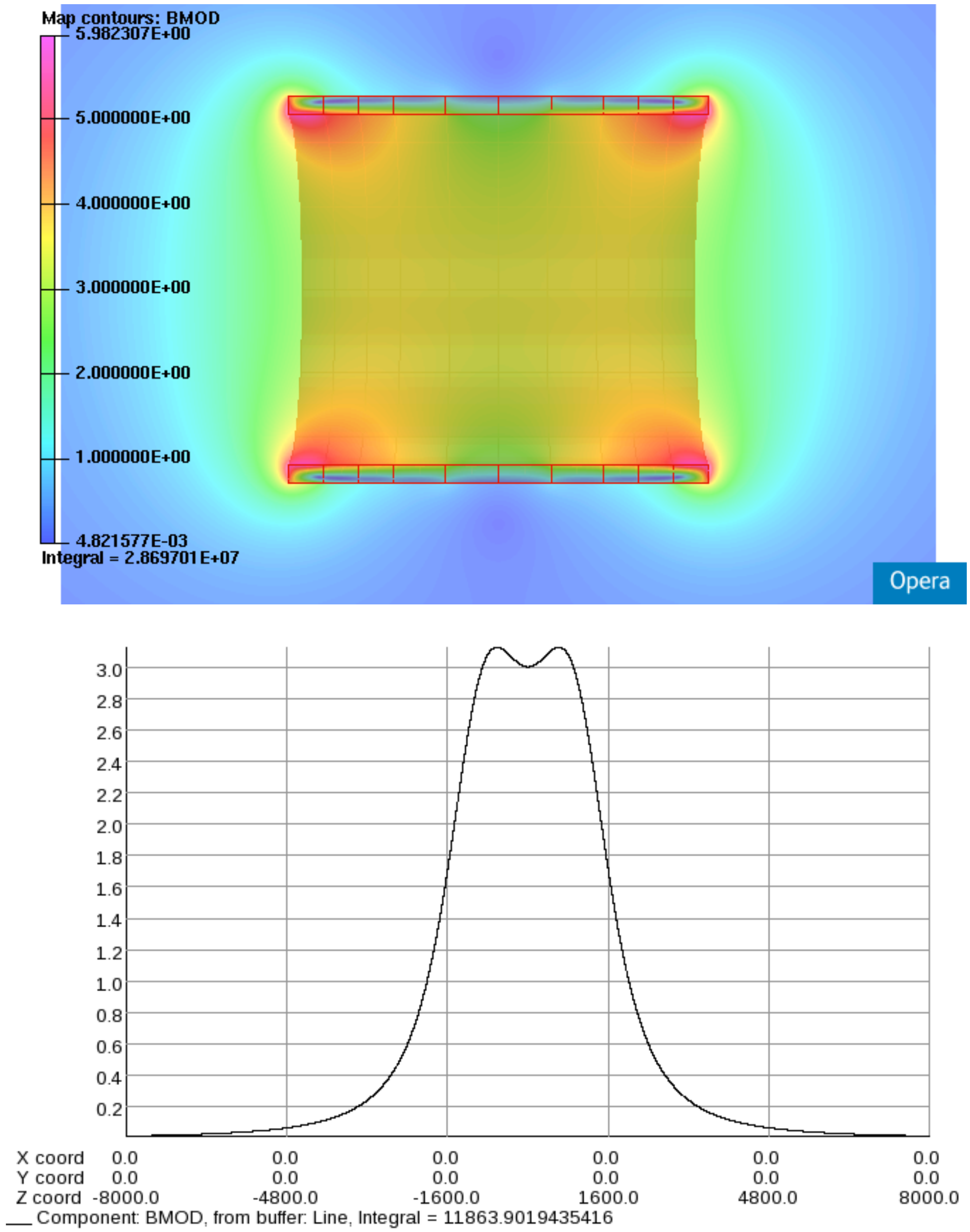


Fig. 1C – Magnetic field modulus mapping for the MRS-B1. The central field strength (x=0, y=0, z = 0) is 3.001 T. The top diagram shows magnetic field strength with a color scale in units of Tesla on the y-z plane. The red box outlines show the boundaries of the magnet. The bottom diagram shows the magnetic field modulus in Tesla along the z-axis from z=±8000 mm. The magnet spans z=± 1200 mm. The plots were constructed with 600 x 600 resolution in the OPERA Post-Processor.

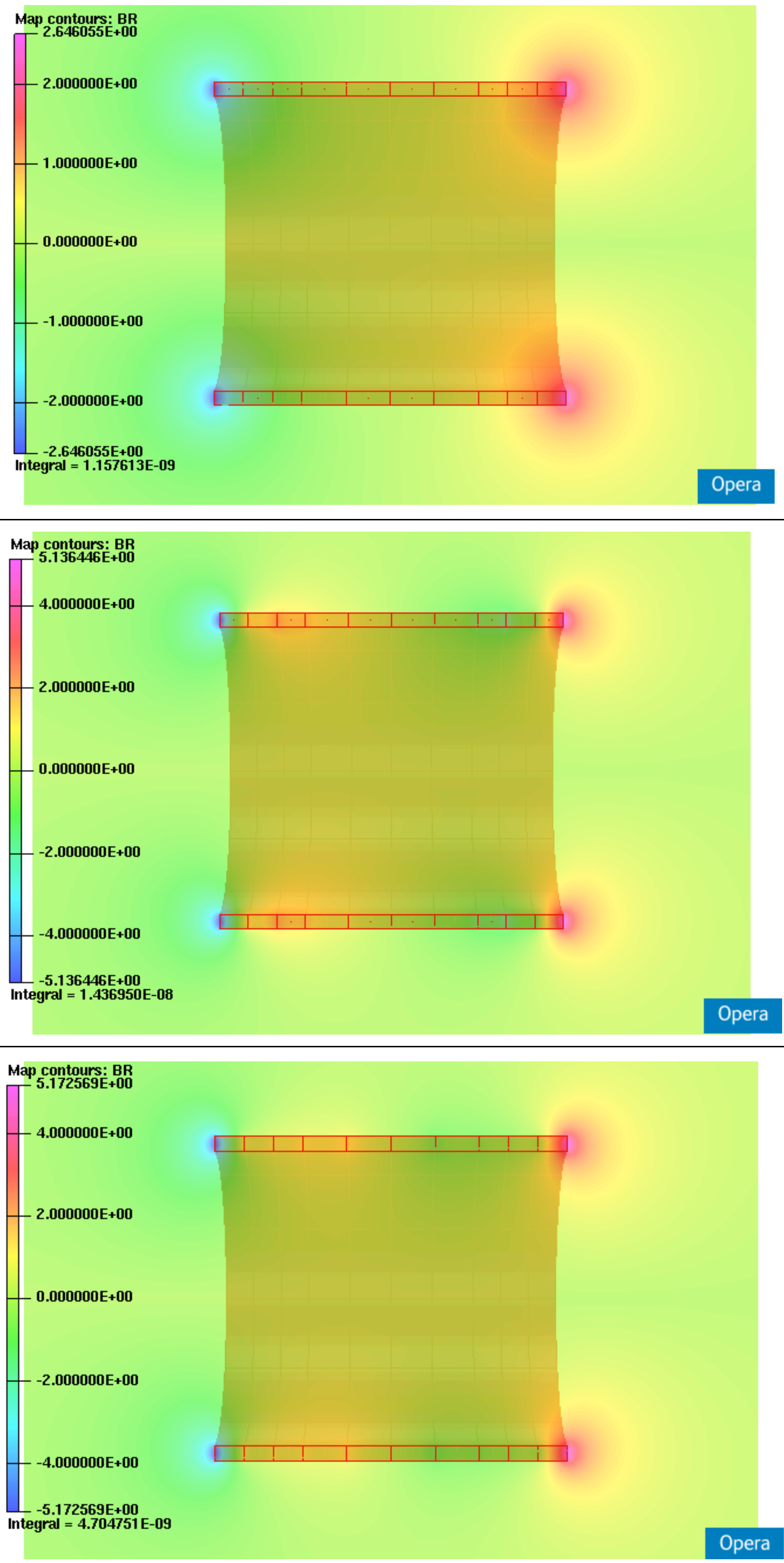


Fig. 1D – Radial magnetic field mapping for the MRS designs. Shown from top to bottom: MRS-A, MRS-B, and the MRS-B1. The maps show radial magnetic field with a color scale in units of Tesla on the y-z plane. The red box outlines show the boundaries of the magnet. All plots were constructed with 600 x 600 resolution in the OPERA Post-Processor.

Simple Solenoid & MRS Analysis- A simple solenoid (SS) was created in order to test the efficiency of the Multiple Ring Solenoid (MRS) designs. This solenoid was given measurements that were identical to those of the MRS (previous section), with a peak inner magnetic field close to that of the MRS-A.

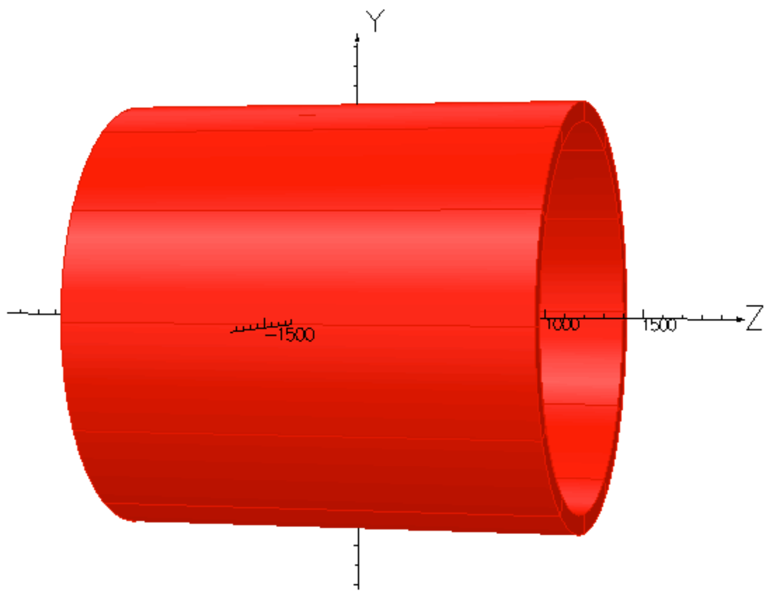


Fig. 2 – The SS design is comprised of a single solenoid.

Total Length – 2.4 m
Inner Radius – 1.0 m
Outer Radius – 1.1 m
Central B field - 3.001 T
Peak Radial B - 2.522 T

The current density of the SS is 31.73 A/mm^2, which yields a peak central magnetic field of 3.0 T. Particle trajectories for 5GeV and 10GeV electrons were simulated with both designs at angles of 2 and 10 degrees with respect to the z-axis, as measured in the x-z plane. The locations of the particles along the y-axis at z=1200 mm may be seen in Table 2.

Table 2- Particle Trajectory Simulations
Simple Solenoid (SS) vs. Multi-Ring Solenoid (MRS-A & MRS-B)

		Particle locations on y-axis at z=1200 mm		
Particle Energy	Trajectory Angle	SS	MRS-A	MRS-B
5 GeV	2^0	3.92 ± 0.01 mm	3.95 ± 0.05 mm	3.50 ± 0.05 mm
	10^0	20.11 ± 0.02 mm	20.30 ± 0.01 mm	17.97 ± 0.01 mm
10 GeV	2^0	1.96 ± 0.01 mm	1.98 ± 0.01 mm	1.75 ± 0.01 mm
	10^0	10.05 ± 0.05 mm	10.18 ± 0.02 mm	9.00 ± 0.02 mm

The z-coordinate 1200 mm was chosen because it is the end of the solenoid, and likely where an end-cap detector would be placed. Bending in the y-plane is due only to the magnetic field since the indicated trajectory angles are only in the x-z plane. Thus, the bending datum would all be zero if the magnetic field were absent. From the data, it may be ascertained that the MRS-A design provides more bending to particle trajectories than a similar simple solenoid.

The effectiveness of increasing the gradient between solenoid fields and increasing the radial field at the ends of the solenoid may be seen in a comparison between the MRS-A and MRS-B1 designs in Table 2A.

Table 2A- Particle Trajectory Simulations Multi-Ring Solenoid (MRS-A & MRS-B1)			
		Particle locations on y-axis at z=1200 mm	
Particle Energy	Trajectory Angle	MRS-A	MRS-B1
5 GeV	2^0	3.95 ± 0.01 mm	4.51 ± 0.01 mm
	10^0	20.30 ± 0.02 mm	23.18 ± 0.02 mm
10 GeV	2^0	1.98 ± 0.02 mm	2.26 ± 0.02 mm
	10^0	10.18 ± 0.02 mm	11.62 ± 0.02 mm

As can be noted from the data, the MRS-B1 design is more effective than the MRS-A design. In Fig. 2B-2C, the values of $\int B_{mod} * dz$ may be seen for the MRS-A and MRS-B1 designs. Note the "bunny ears" that occur in the profile of the magnetic field modulus as mapped along the z-axis (Fig. 2C). These ears increase the value of $\int B_{mod} * dz$, which in general increases the bending angles of particles[1].

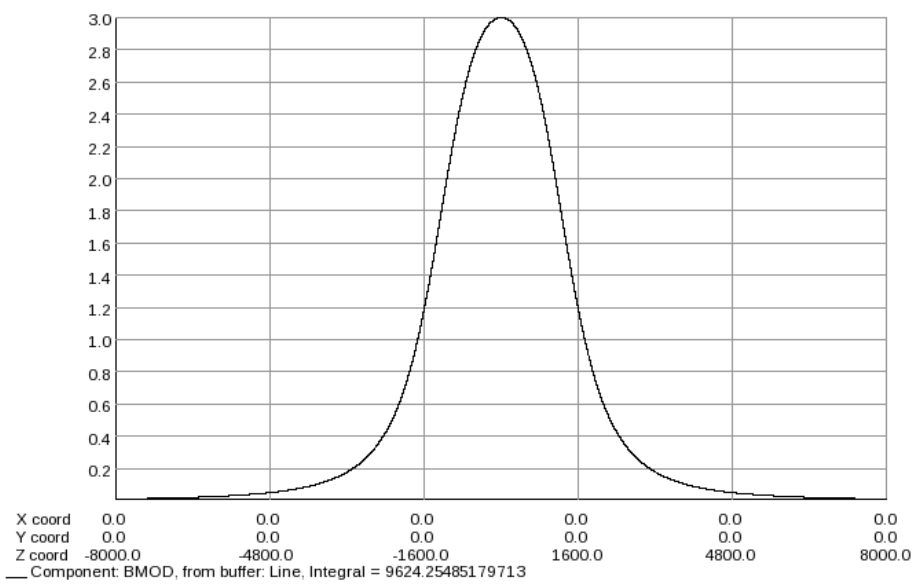


Fig. 2B – This is a plot of $\int B_{mod} * dz$ for the MRS-A design, with the vertical axis in units of Tesla, and the horizontal axis in units of millimeters. The Value of the integral is ~9.6 Tm.

[1] A. Yamamoto, Nucl. Intrs. And Meth. A 453 (2000) p. 445-454.

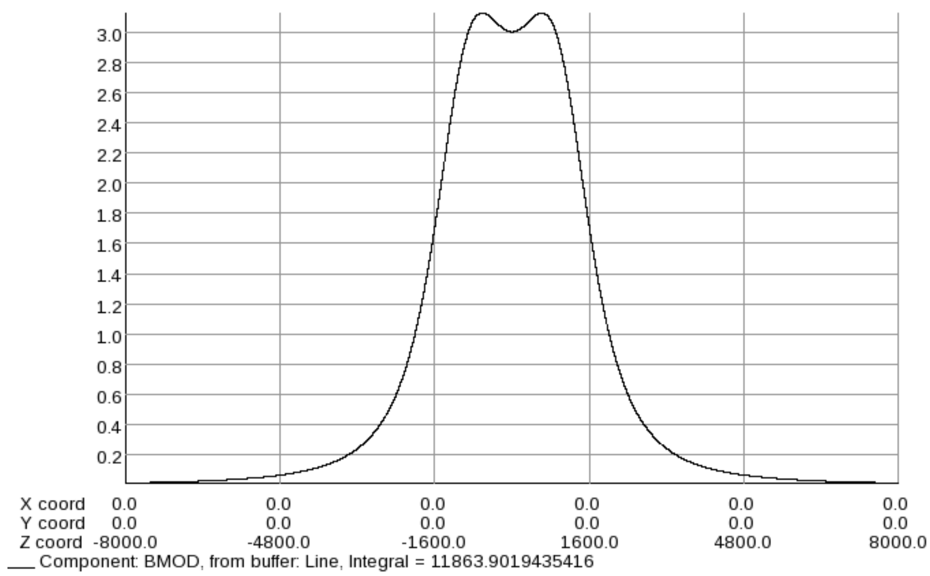


Fig. 2C – This is a plot of $\int B_{mod} * dz$ for the MRS-B1 design, with the vertical axis in units of Tesla, and the horizontal axis in units of millimeters. The Value of the intrgral is ~11.9 Tm. Notice the ~3.1 T "bunny ears" to the left and right of the central B-field value of 3.0 T.

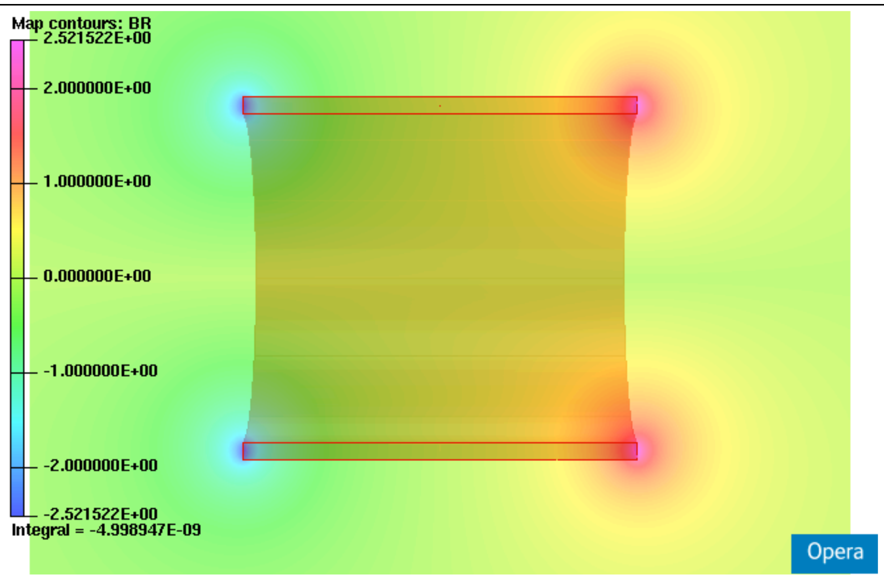
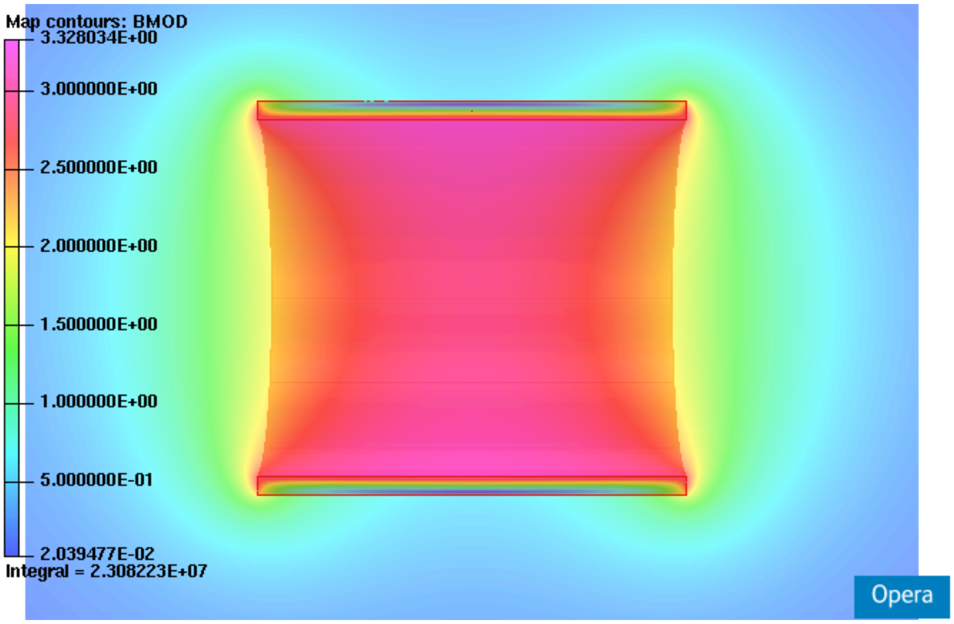


Fig. 2D – This is a map of the radial magnetic field for the SS design. The map shows radial magnetic field with a color scale in units of Tesla on the y-z plane. The plots were constructed with 600 x 600 resolution in the OPERA Post-Processor.



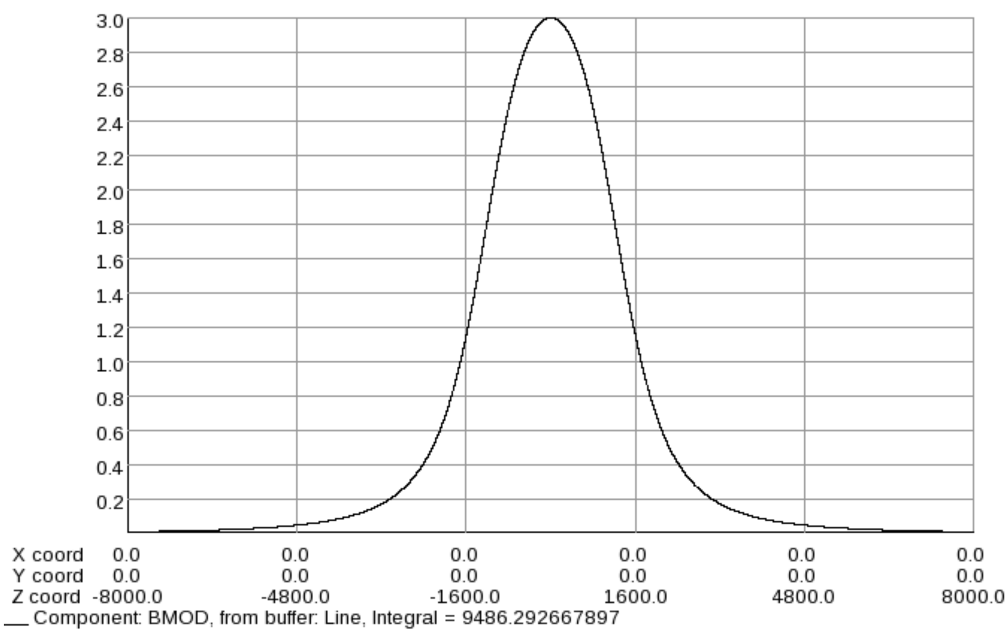


Fig. 2E – Magnetic field modulus mapping for the SS. The central field strength (x=0, y=0, z = 0) is 3.001 T. The top diagram shows magnetic field strength with a color scale in units of Tesla on the y-z plane. The red box outlines show the boundaries of the magnet. The bottom diagram shows the magnetic field modulus in Tesla along the z-axis from z=±8000 mm. The magnet spans z=± 1200 mm. The plots were constructed with 600 x 600 resolution in the OPERA Post-Processor.

Dipole-Solenoid- Another design that was explored involves a solenoid with two dipoles at either end, the Dipole-Solenoid (DS) (Fig. 3).

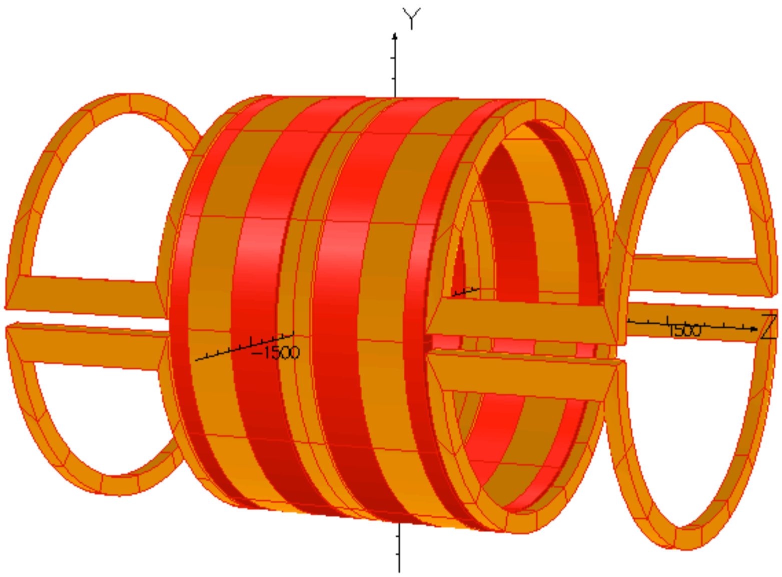


Fig. 3A – The DS design is comprised of four solenoid pairs and one dipole reflected across the x-y and z-x planes. The inner solenoid pair (yellow colored, along y-axis) is labeled as S1, with the dipoles listed as D.

Total Length – 3.4 m
Inner Radius – 1.0 m
Outer Radius – 1.1 m
Central B field - 3.001 T
Peak Radial B – 4.635 T

The overall length of the DS design is 3.4 m with an inner radius of 1.0 m and an outer radius of 1.1 m (Fig. 3). The current densities are lowest in solenoid pair 1, S1, and greatest in S4, the last pair before the dipoles (Table 3). This solenoid setup yields a peak central magnetic field (x=0, y=0, z=0) of 3.0 T. This design introduces magnetic fields that are perpendicular to the ones generated by the solenoid. The peak radial field value of 4.5 T is due to the high current densities in solenoid pairs S1-S4, as shown in Table 3.

Table 3A – Current Densities of Magnet Sets for DS Design

Magnet Set	Current Density
S1	31.6 A/mm^2
S2	40.0 A/mm^2
S3	50.0 A/mm^2
S4	60.0 A/mm^2
D	30.0 A/mm^2

The DS design was modified by placing the dipoles around the solenoids, as per a design presented by Dr. Brett Parker. The Dipole-Wrapped Solenoid (DWS) is very similar to the design presented by Dr. Parker. The DWS is more compact than the DS, so particle trajectories were not performed at the same location along the z-axis (Table 3C).

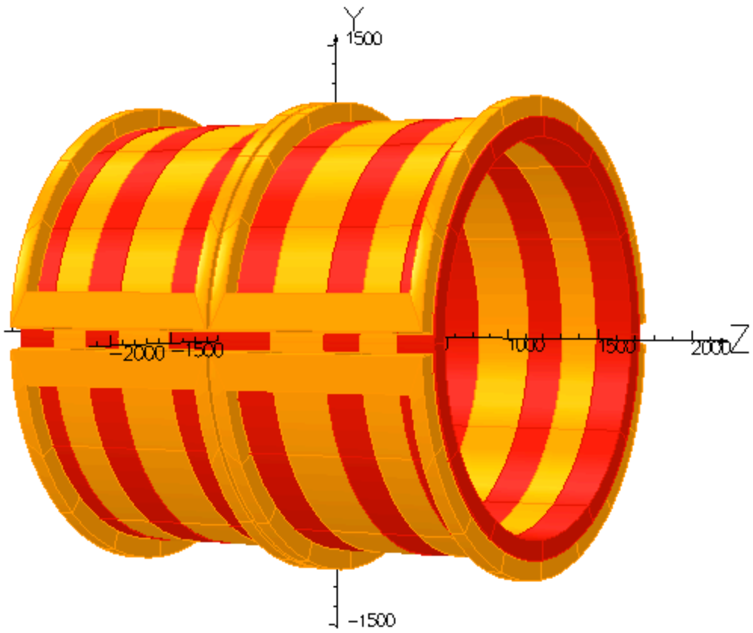


Fig. 3B – The DWS design is comprised of five solenoid pairs The inner solenoid pair (red colored, along y-axis) is labeled as P1, with the dipoles listed as D.

Total Length – 2.4 m
Inner Radius – 1.0 m
Outer Radius – 1.1 m
Central B field - 3.002 T
Peak Radial B - 5.097 T

Table 3B – Current Densities of Magnet Sets for DWS Design

Magnet Set	Current Density
P1	19.15 A/mm^2
P2	30.00 A/mm^2
P3	40.00 A/mm^2
P4	50.00 A/mm^2
P5	80.00 A/mm^2
D	25.00 A/mm^2

Table 3C- Particle Trajectory Simulations
Dipole-Solenoid Designs (DS & DWS)

		Particle locations on y-axis at magnet end	
Particle Energy	Trajectory Angle	DS z=1700 mm	DWS z=1200 mm
5 GeV	2^0	6.14 ± 0.01 mm	4.57 ± 0.01 mm
	10^0	29.93 ± 0.01 mm	23.44 ± 0.01 mm
10 GeV	2^0	2.99 ± 0.01 mm	2.29 ± 0.01 mm
	10^0	14.91 ± 0.01 mm	11.76 ± 0.01 mm

Particle trajectories measured at the same location along the z-axis may be seen in Table 3D. The new DS measurements coincide with the end of the DWS design and about halfway through the DS design's dipoles.

Table 3D- Particle Trajectory Simulations Dipole-Solenoid Designs (DS & DWS)			
		Particle locations on y-axis at z=1200 mm	
Particle Energy	Trajectory Angle	DS	DWS
5 GeV	2^0	3.63 ± 0.01 mm	4.57 ± 0.01 mm
	10^0	18.10 ± 0.01 mm	23.44 ± 0.01 mm
10 GeV	2^0	1.79 ± 0.01 mm	2.29 ± 0.01 mm
	10^0	9.03 ± 0.01 mm	11.76 ± 0.01 mm

Although truncating the DS design data seems unfair in comparing the two models, the compactness is a favorable attribute as far as cooling and instrumentation placement is concerned. The truncation on the DS trajectories eliminates data affected by approximately 0.544 Tm (z=1200 mm to z=1800 mm) when moving through an angle of 10-degrees at 5 GeV. Initially the particle experiences 2.802 Tm (z= 0 mm to z=1200 mm). In the DWS design, the particle experiences approximately 3.650 Tm over a 10-degree trajectory at 5GeV.

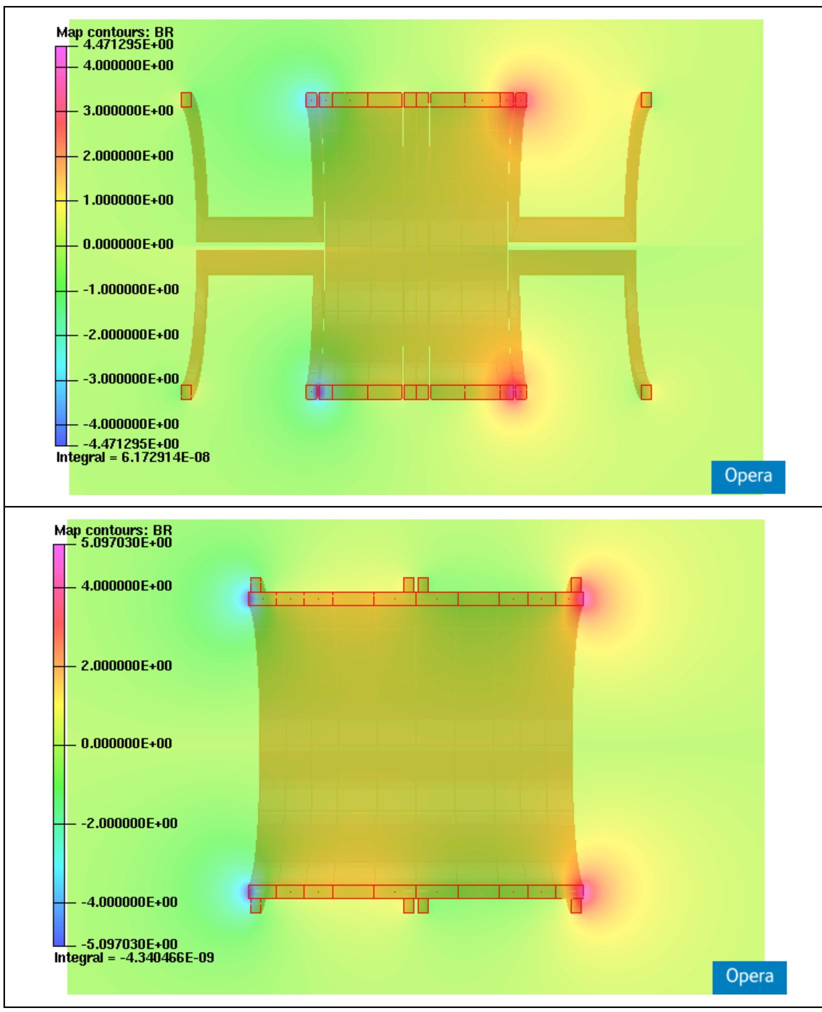


Fig. 3E – Radial magnetic field mapping for the DW and DWS designs. Shown from top to bottom: DW and DWS. The maps show radial magnetic field with a color scale in units of Tesla on the y-z plane. The red box outlines show the boundaries of the magnet. All plots were constructed with 600 x 600 resolution in the OPERA Post-Processor.

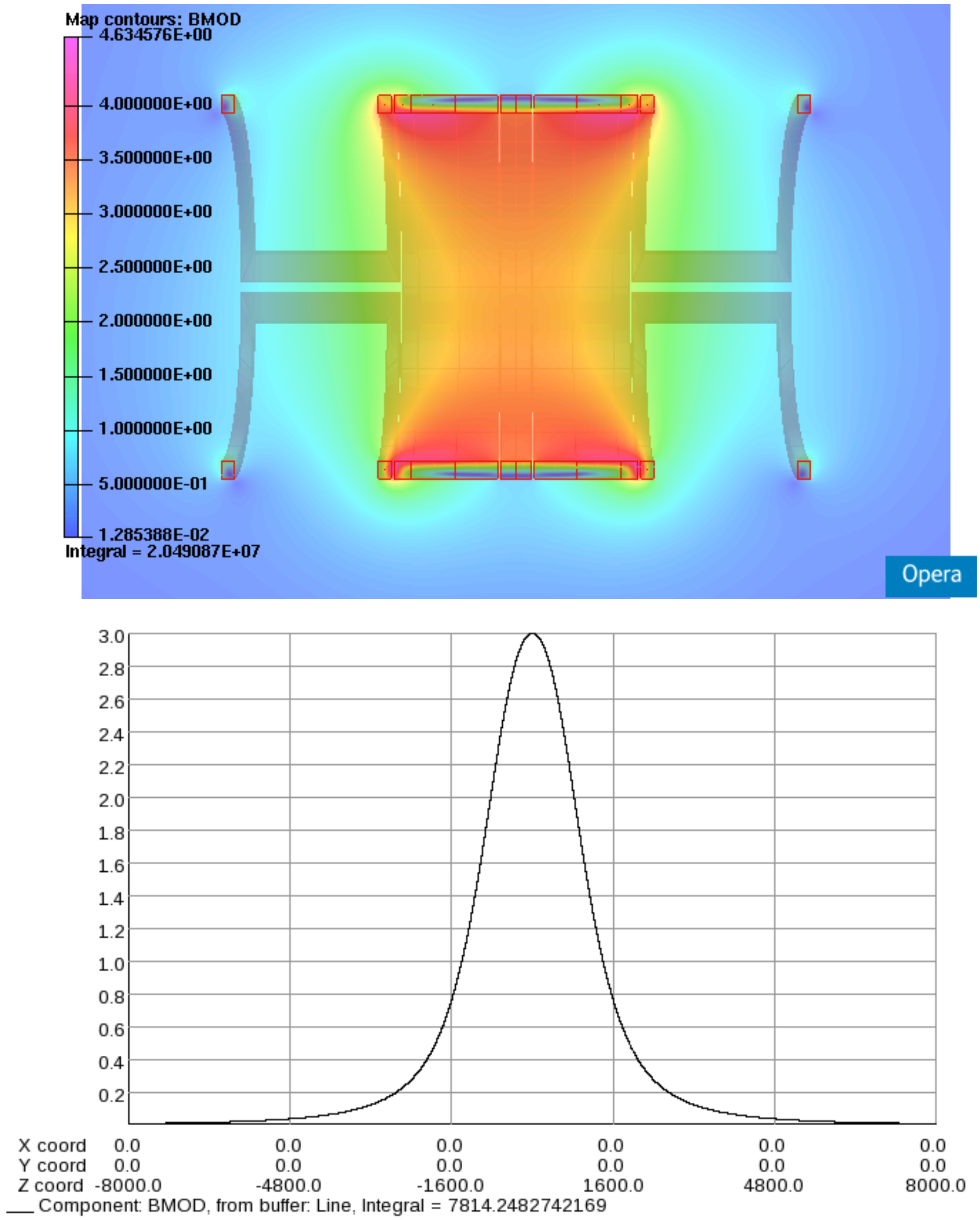


Fig. 3F – Magnetic field modulus mapping for the DS design. The central field strength (x=0, y=0, z = 0) is 3.001 T. The top diagram shows magnetic field strength with a color scale in units of Tesla on the y-z plane. The red box outlines show the boundaries of the magnet. The bottom diagram shows the magnetic field modulus in Tesla along the z-axis from z=±8000 mm. The magnet spans z=± 1700 mm. The plots were constructed with 600 x 600 resolution in the OPERA Post-Processor.

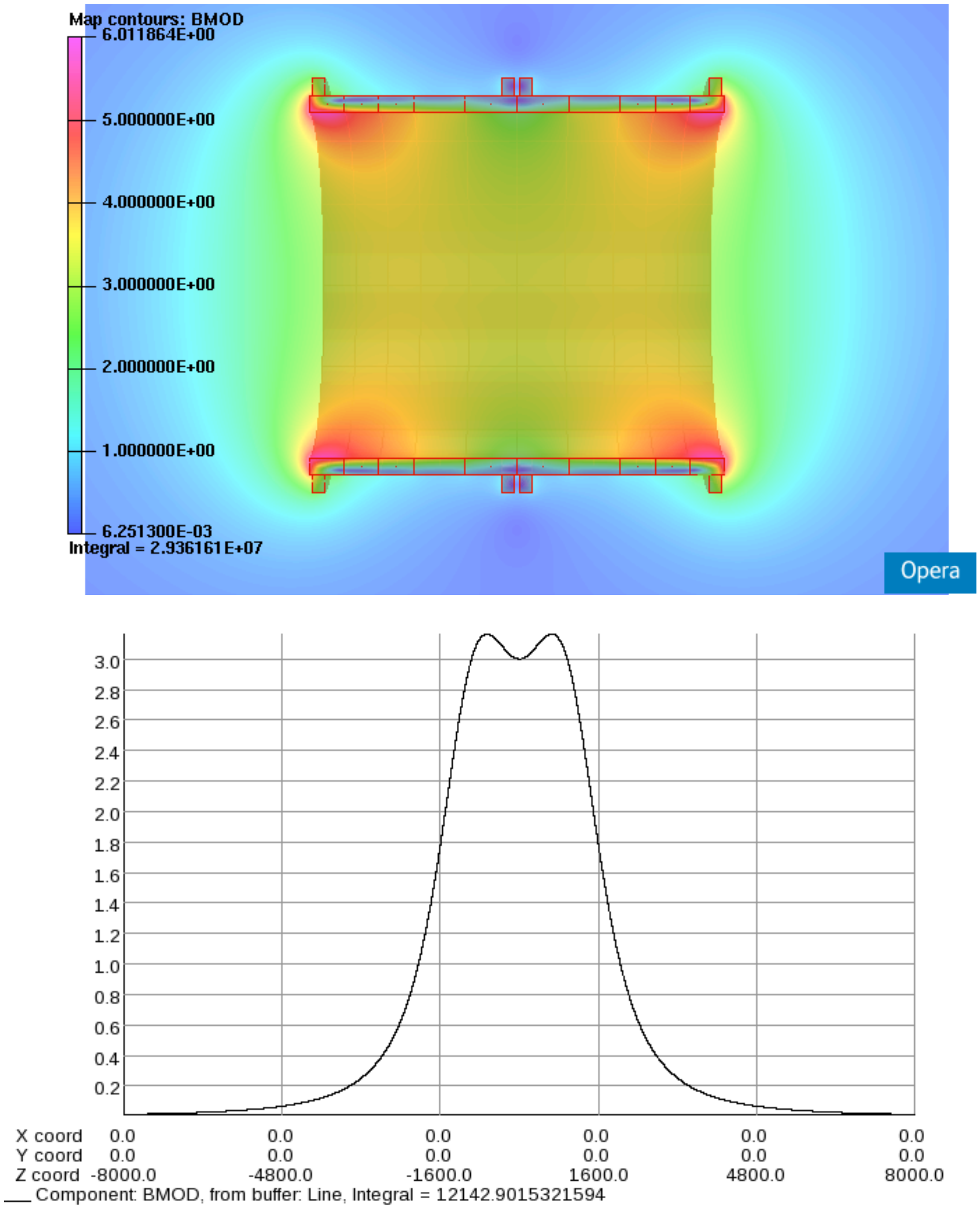
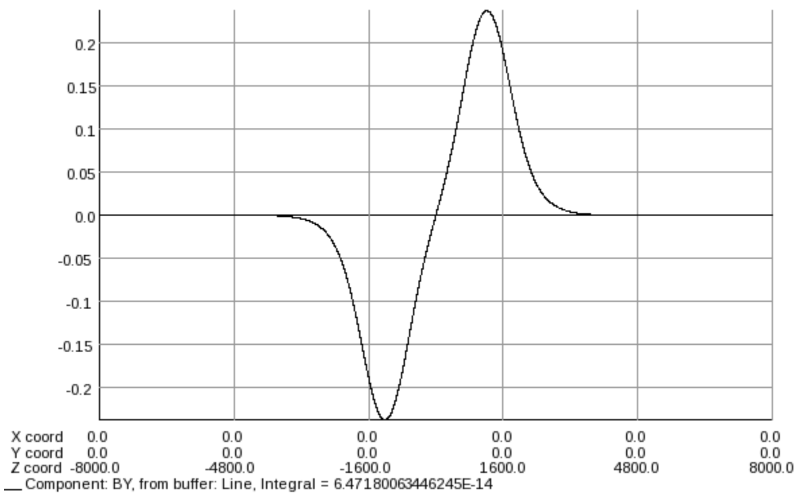


Fig. 3G – Magnetic field modulus mapping for the DWS design. The central field strength (x=0, y=0, z = 0) is 3.001 T. The top diagram shows magnetic field strength with a color scale in units of Tesla on the y-z plane. The red box outlines show the boundaries of the magnet. The bottom diagram shows the magnetic field modulus in Tesla along the z-axis from z=±8000 mm. The magnet spans z=± 1200 mm. The plots were constructed with 600 x 600 resolution in the OPERA Post-Processor.



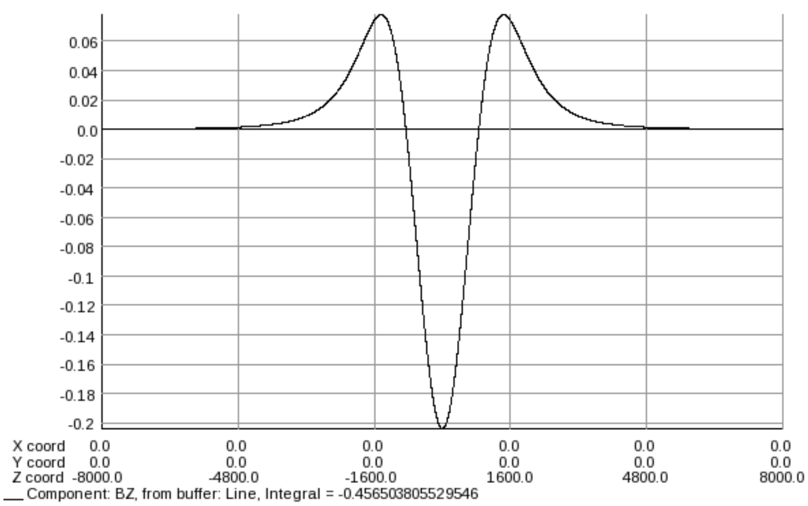


Fig. 3H – Magnetic field plots showing the magnetic field y- and z-components of the DS and DWS designs, respectively. Shown from top to bottom: DS y-component and DWS z-component. The maps show magnetic field on the vertical scale in units of Tesla as a function of position along the z-axis in millimeters. Other axes are excluded because their peak magnetic field values were of order 10^-17 T.

Coaxial Ring System – Designs inspired by the Fourth Concept Detector[2] were also utilized. The Fourth Concept Detector (FCD) was a proposed ILC detector implementing a solenoid within a solenoid to provide shielding and containment of the generated magnetic field. The idea of a self-shielding magnet was implemented in the design of the Coaxial Ring System (CoRiS) and its permutations (Fig. 4A-4B).

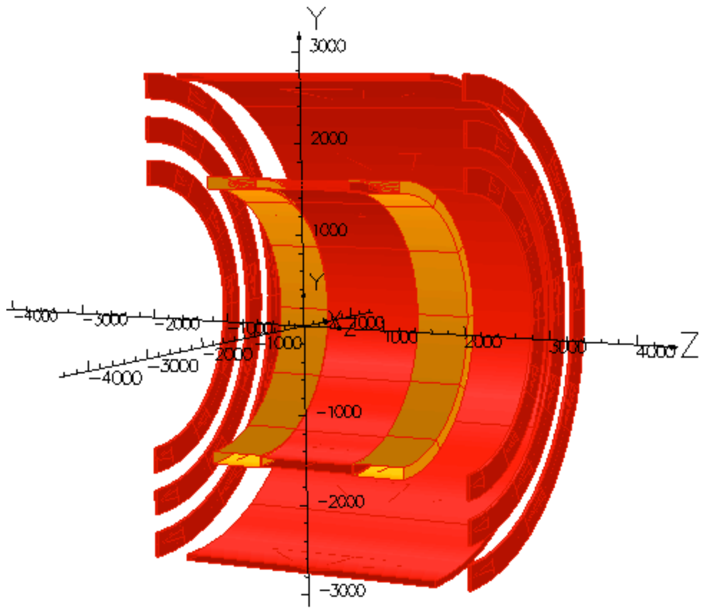


Fig. 4A – The CoRiS design is comprised of four central solenoids and three pairs of rings. The CoRiS-A design, shown here in a cross-sectional view, has an inner solenoid radius of 1.5 m. The yellow magnets are the Helmholtz coils, H-Z ad H+Z.

Total Length, Outer – 4.08 m
Total Length, Inner – 2.4 m
Helmholtz Width – 638.5 mm
InnerSol Radius – 1.5 m
OuterSol Radius – 5.38 m
Central B field – 3.008 T
Peak Radial B – 5.807 T

The inner solenoid is INNERSOL, the outer solenoid is OUTERSOL, and the flat outer solenoid pairs, rings, are labeled as R1-R3 with R1 closest to the z-axis. The Helmholtz coils flank the INNERSOL and are labeled as H-Z and H+Z for the Helmholtz coils on the negative and positive z-axes, respectively. The three innermost solenoids are coaxial, while the outer solenoid is oriented with its magnetic field opposite to the inner solenoids and coaxial with the rings. Only radii and current densities were varied with CoRiS permutations (A and B are listed herein). Particle trajectories for 5GeV and 10GeV electrons were simulated through the designs at angles of 2 and 10 degrees with respect to the z-axis as measured in the x-z plane.

Table 4A – Current Densities of Magnets for CoRiS-A Design

Magnet	Current Density
INNERSOL	20.74 A/mm^2
OUTERSOL	14.50 A/mm^2
H+Z and H-Z	62.30 A/mm^2
R1	34.00 A/mm^2
R2	37.00 A/mm^2
R3	18.00 A/mm^2

[2] http://www.4thconcept.org/4LoI.pdf

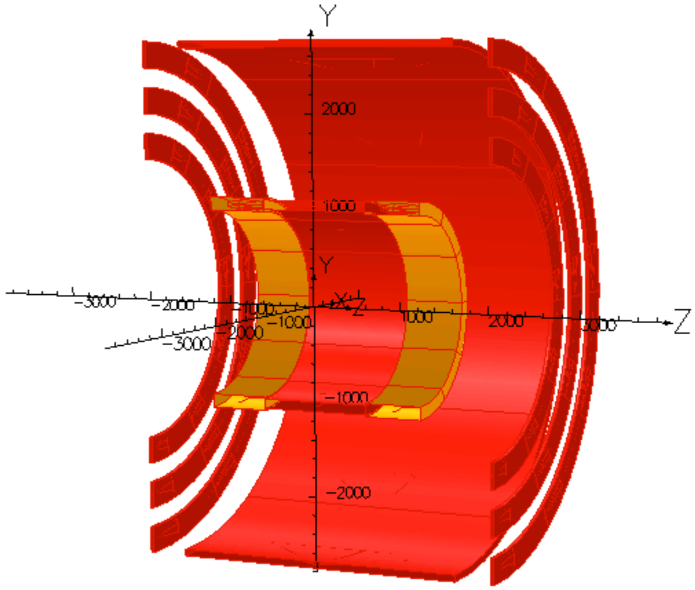


Fig. 4B – The CoRiS-B design, shown here in a cross-sectional view, has a smaller inner solenoid radius of 1.0 m.

Total Length, Outer – 4.08 m
Total Length, Inner – 2.4 m
Helmholtz Width – 638.5 mm
InnerSol Radius – 1.0 m
OuterSol Radius – 5.38 m
Central B field – 3.000 T
Peak Radial B – 3.660 T

Table 4B – Current Densities of Magnets for CoRiS-B Design	
Magnet	Current Density
INNERSOL	26.5 A/mm^2
OUTERSOL	7.0 A/mm^2
H+Z and H-Z	39.0 A/mm^2
R1	34.0 A/mm^2
R2	37.0 A/mm^2
R3	18.0 A/mm^2

Particle bendings for the CoRiS permutations are shown in Table 4C. The ideal location for an endcap particle detector on any CoRiS design would be around the z-axis, surrounded by R1, at z=2020 mm.

Table 4C- Particle Trajectory Simulations Coaxial Ring System (CoRiS-A & CoRiS-B)			
		Particle locations on y-axis at z=2020 mm	
Particle Energy	Trajectory Angle	CoRiS-A	CoRiS-B
5 GeV	2^0	9.90 ± 0.01 mm	9.17 ± 0.01 mm
	10^0	50.70 ± 0.02 mm	46.88 ± 0.02 mm
10 GeV	2^0	4.98 ± 0.02 mm	4.60 ± 0.02 mm
	10^0	25.50 ± 0.02 mm	23.56 ± 0.02 mm

The scaled down version of the FCD (miniature FCD or mFCD) is also included for completeness in the appendix. When the FCD was first examined, it appeared that the self-shielding from the outer solenoid and rings would provide a high magnetic field gradient and thus a high radial field at the ends of the inner solenoid. In the CoRiS designs, large volumes were found to have radial field near the inner solenoid ends, but they do not overlap with the region where radial field is most desired. In both the full size and scaled down (four meters by three meters, eRHIC experimental space) version of the FCD we found magnetic field values within the surfaces of the conductors exceeding 6 T. In practice, having fields higher than 6 T in the superconducting material can cause melting and/or other adverse effects. In addition, the FCD was optimized to have muon tracking in between the inner and outer solenoids, using a “secondary” magnetic field; this is not so important for the eRHIC project, thus we lowered the value of the secondary magnetic field in the CoRiS permutations. These issues led us to abandon the FCD and CoRiS designs as an option.

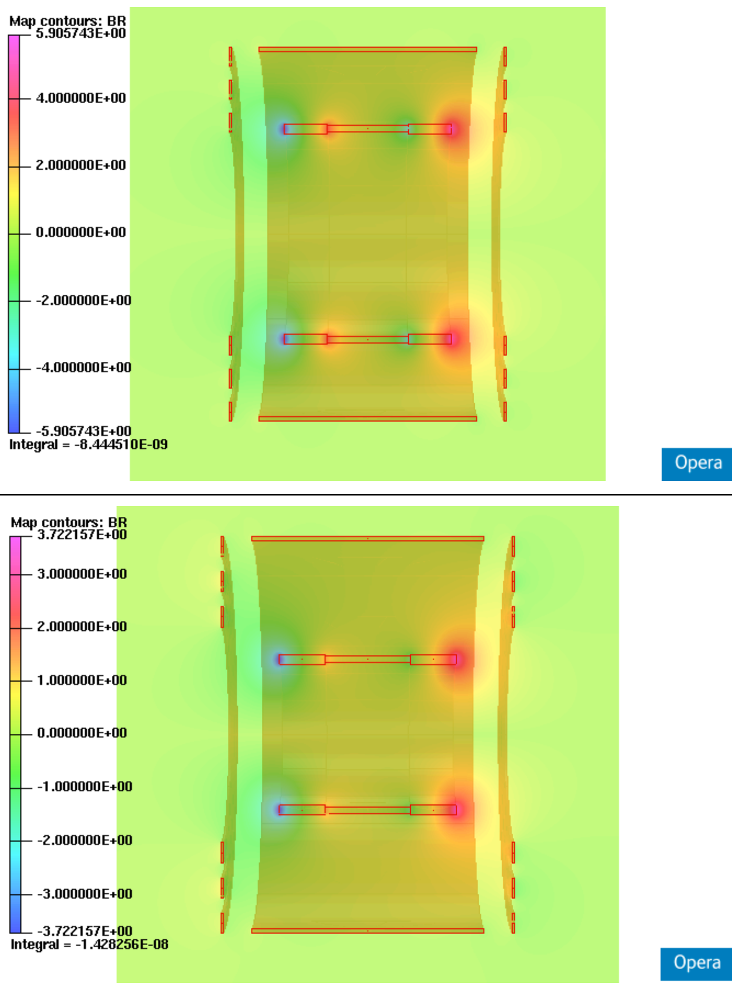


Fig. 4D – Radial magnetic field mapping for the CoRiS designs. Shown from top to bottom: CoRiS-A and CoRiS-B. The maps show radial magnetic field with a color scale in units of Tesla on the y-z plane. The red box outlines show the boundaries of the magnet. All plots were constructed with 600 x 600 resolution in the OPERA Post-Processor.

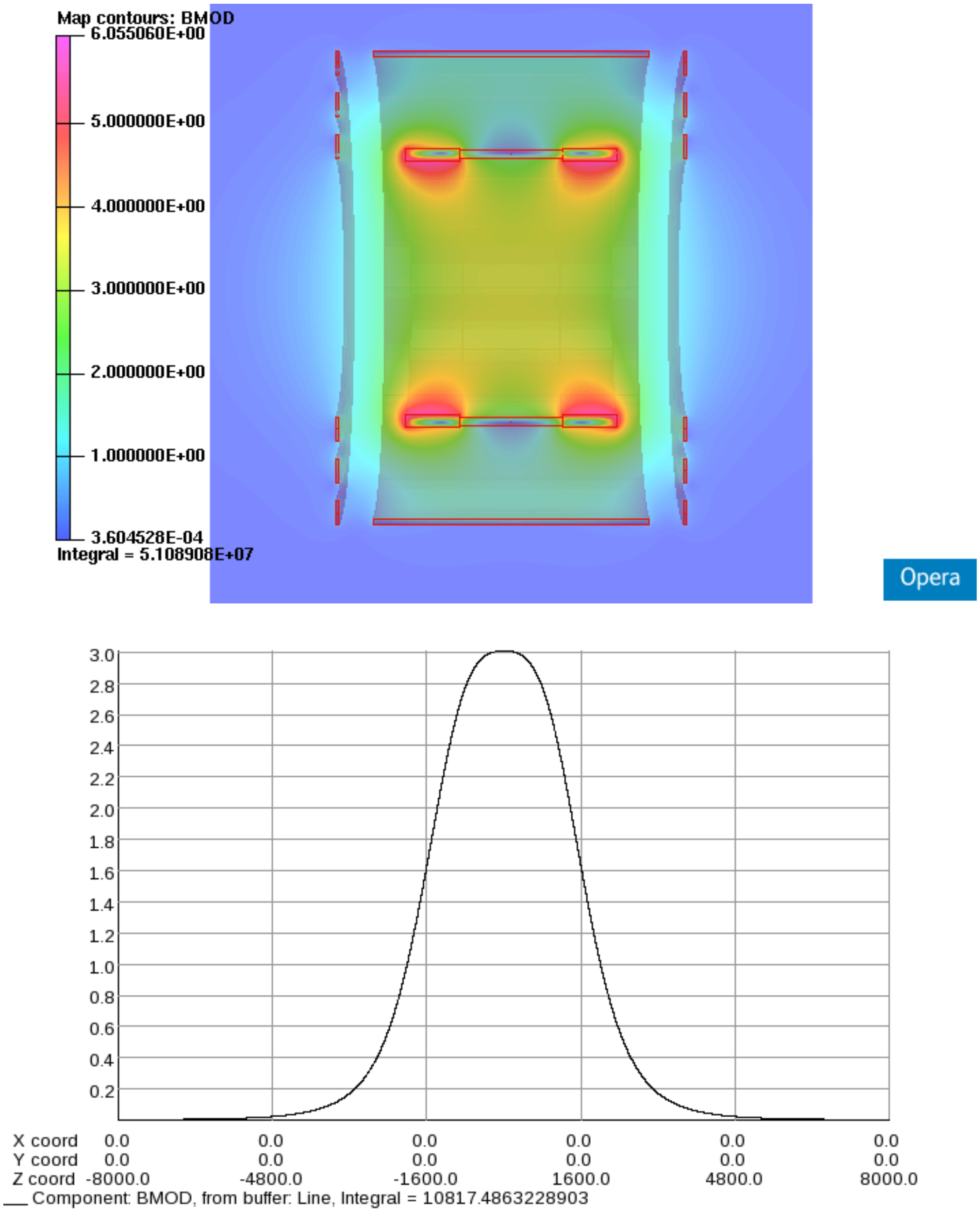


Fig. 4E – Magnetic field modulus mapping for the CoRiS-A design. The central field strength (x=0, y=0, z = 0) is 3.008 T. The top diagram shows magnetic field strength with a color scale in units of Tesla on the y-z plane. The red box outlines show the boundaries of the magnet. The bottom diagram shows the magnetic field modulus in Tesla along the z-axis from z=±8000 mm. The magnet spans z=± 2044.9 mm. The plots were constructed with 600 x 600 resolution in the OPERA Post-Processor.

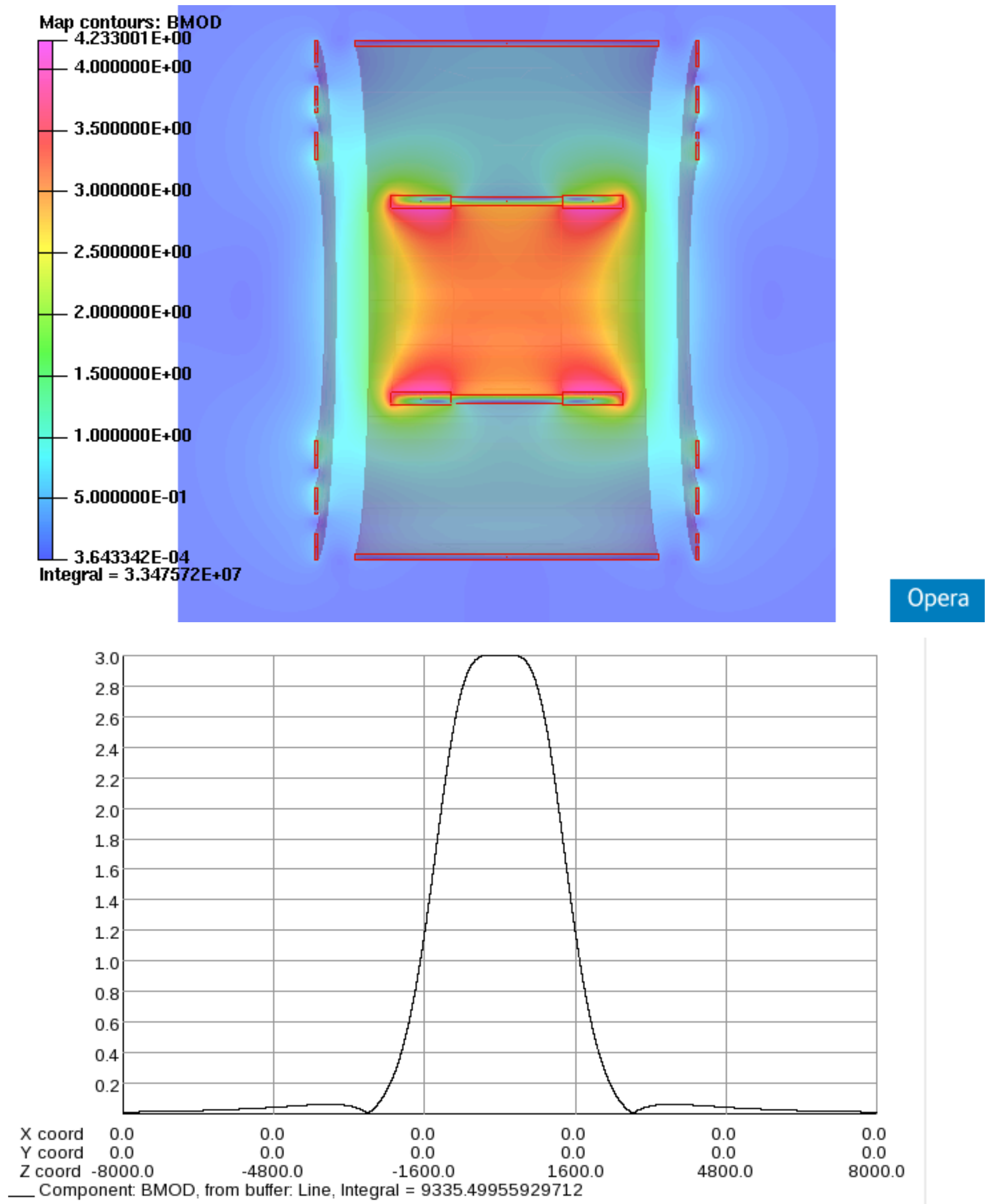


Fig. 4F – Magnetic field modulus mapping for the CoRiS-B design. The central field strength (x=0, y=0, z = 0) is 3.000 T. The top diagram shows magnetic field strength with a color scale in units of Tesla on the y-z plane. The red box outlines show the boundaries of the magnet. The bottom diagram shows the magnetic field modulus in Tesla along the z-axis from z=±8000 mm. The magnet spans z=± 2044.9 mm. The plots were constructed with 600 x 600 resolution in the OPERA Post-Processor.

Strobili Solenoid **–** Attempts to guide a solenoidal field away from the central axis to create radial components led to the Strobili Solenoid (StrobS). The name implies the cone-like arrangement of the solenoid rings (Fig. 5A-5B).

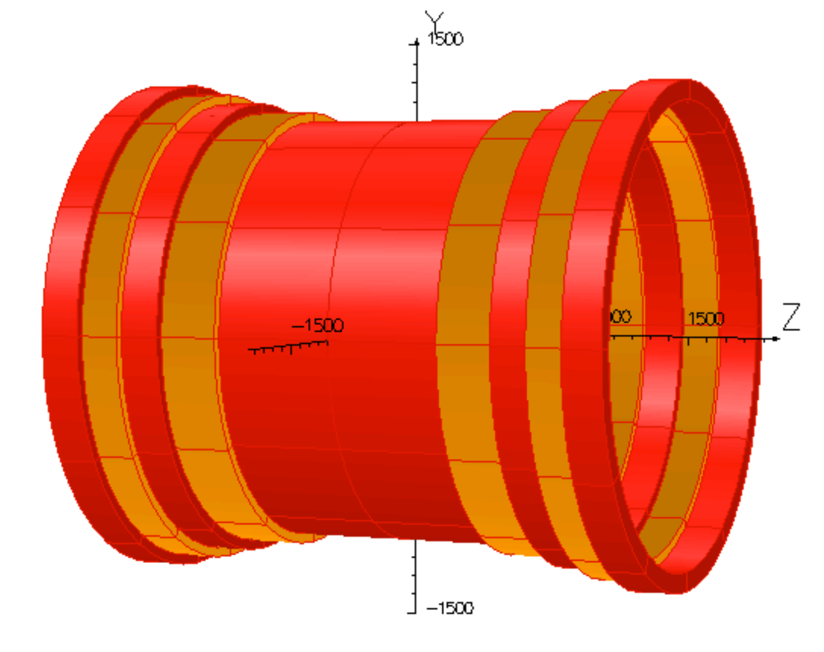


Fig. 5A – The StrobS-A design has five solenoid pairs (P1-P5).

Total Length – 3.0 m
Initial Radius (P1) – 1.0 m
Ending Radius (P5) – 1.2 m
Central B field - 3.001 T
Peak Radial B - 5.423 T

The magnetic field gradient experimented with in the MRS designs was also implemented in the StrobS designs. The central field modulus (x=0, y=0, z=0) of the StrobS-A is set to 3.0 T, close to most of the other designs experimented with. The StrobS-A has a peak radial field of 5.4 T. The StrobS-A design has a current density scheme similar to that of the MRS-B1.

Table 5A – Current Densities of Magnets for StrobS-A Design

Magnet	Current Density
P1	18.06 A/mm^2
P2	30.50 A/mm^2
P3	40.00 A/mm^2
P4	50.00 A/mm^2
P5	90.00 A/mm^2

The StrobS-B design has an even more exaggerated change in ring radius (Fig. 5B). Because of the larger radii, it was necessary to raise the current density in the other rings to obtain the familiar ~3 T central magnetic field modulus. The StrobS-B model has a peak central (x=0, y=0, z=0) magnetic field modulus of 3.0 T and a peak radial magnetic field of 5.4 T.

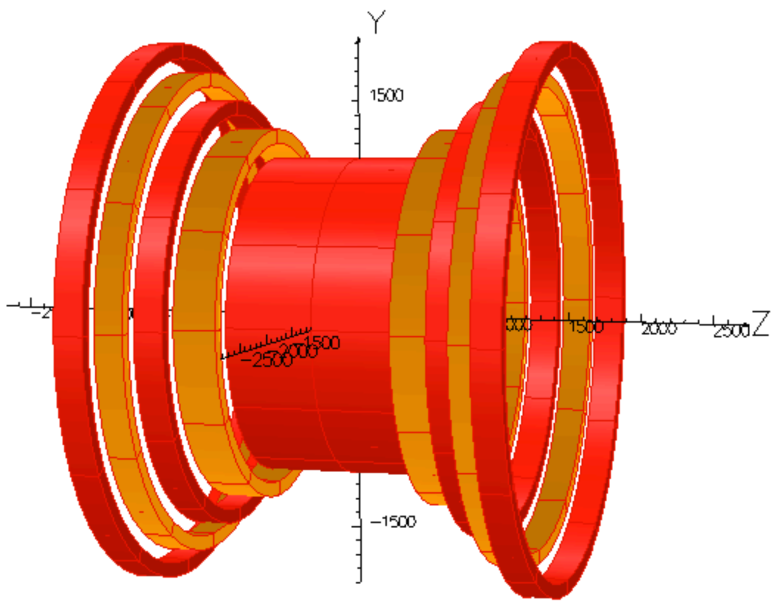


Fig. 5B – The StrobS-B design has five solenoid pairs (P1-P5) with the outer four at much larger radii.

Total Length – 3.0 m
Initial Radius (P1) – 1.0 m
Ending Radius (P5) – 1.8 m
Central B field – 3.001 T
Peak Radial B - 5.446 T

Table 5B – Current Densities of Magnets for StrobS-B Design	
Magnet	Current Density
P1	19.53 A/mm^2
P2	21.00 A/mm^2
P3	30.00 A/mm^2
P4	50.00 A/mm^2
P5	100.00 A/mm^2

The ideal location for an endcap detector would lie at the end of the detector, z=1500 mm. Particle trajectories were simulated for this design, and are summarized in Table 5C.

Table 5C- Particle Trajectory Simulations Strobili Solenoid (StrobS-A & StrobS-B)			
		Particle locations on y-axis at z=1500 mm	
Particle Energy	Trajectory Angle	StrobS-A	StrobS-B
5 GeV	2^0	6.94 ± 0.01 mm	6.19 ± 0.01 mm
	10^0	35.63 ± 0.01 mm	31.72 ± 0.01 mm
10 GeV	2^0	3.49 ± 0.01 mm	3.11 ± 0.01 mm
	10^0	17.90 ± 0.01 mm	15.92 ± 0.02 mm

Originally, the best particle bending was produced by the MRS-B1 design. This prompted a study to compare the bending produced by the MRS-B1 to the StrobS-A design bending at the end coordinate for the MRS-B1 design, z=1200 mm. The results may be seen in Table 5D.

Table 5D- Particle Trajectory Simulations Multi-Ring Solenoid (MRS-B1) vs. Strobili Solenoid (StrobS-A)			
		Particle locations on y-axis at z=1200 mm	
Particle Energy	Trajectory Angle	MRS-B1	StrobS-A
5 GeV	2^0	4.51 ± 0.01 mm	4.56 ± 0.01 mm
	10^0	23.18 ± 0.02 mm	23.39 ± 0.01 mm
10 GeV	2^0	2.26 ± 0.01 mm	2.29 ± 0.01 mm
	10^0	11.62 ± 0.02 mm	11.74 ± 0.02 mm

The StrobS-A design produces more bending in particle trajectories, although the difference varies from 0.1 millimeters to 10 micrometers. The ability to resolve differences this small is limited by the point resolution of the tracking detectors. In addition, the feasibility of constructing a StrobS-A type magnet outweighs the negligible gain in particle bending.

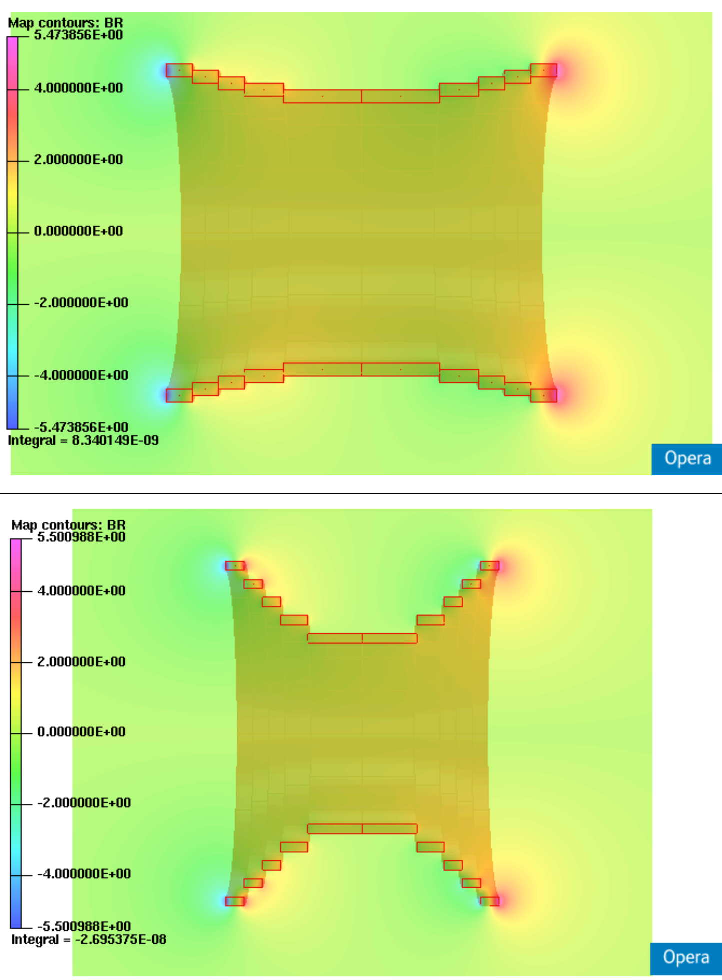


Fig. 5E – Radial magnetic field mapping for the StrobS designs. Shown from top to bottom: StrobS-A and StrobS-B. The maps show radial magnetic field with a color scale in units of Tesla on the y-z plane. The red box outlines show the boundaries of the magnet. All plots were constructed with 600 x 600 resolution in the OPERA Post-Processor.

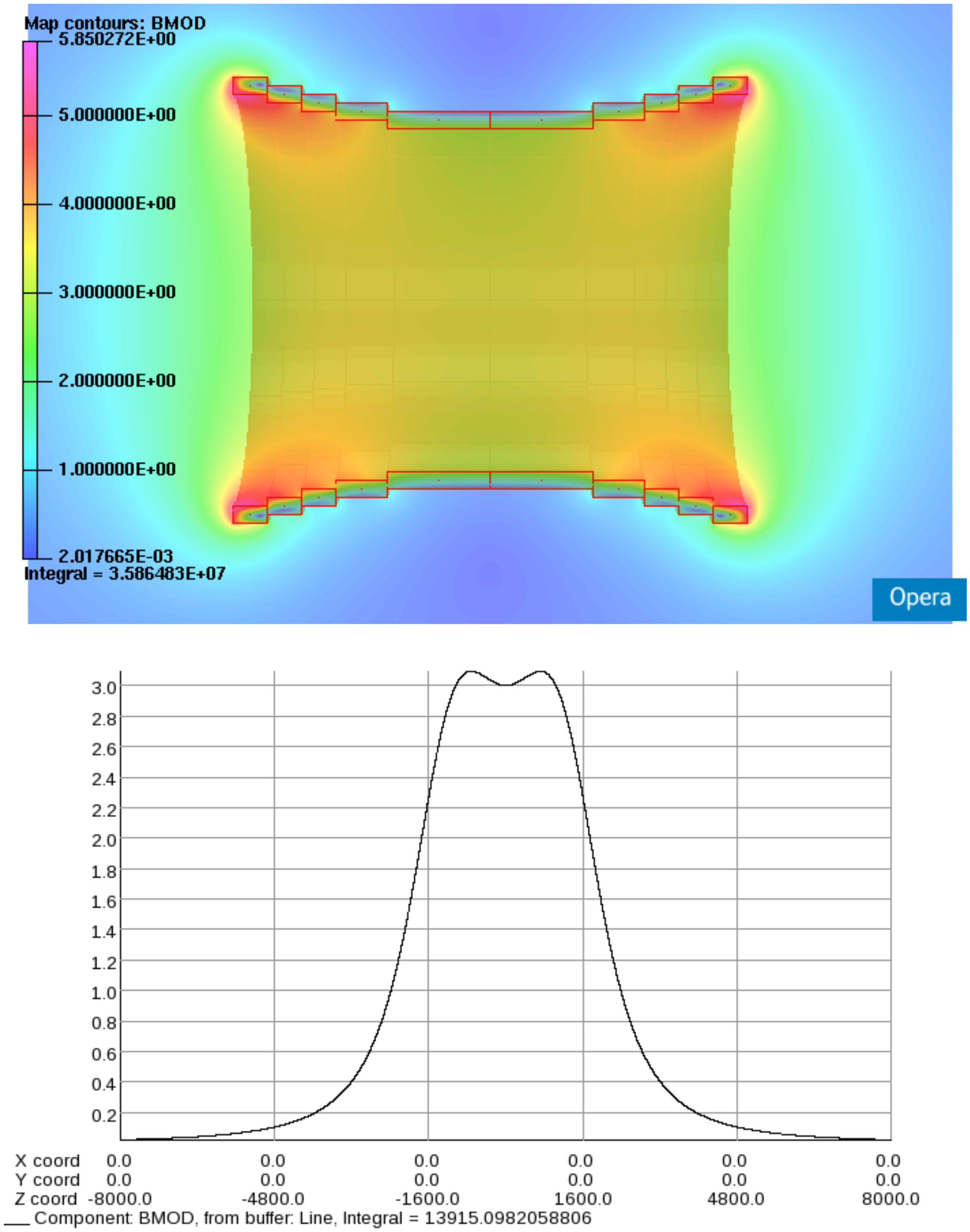


Fig. 5F – Magnetic field modulus mapping for the StrobS-A design. The central field strength (x=0, y=0, z = 0) is 3.001 T. The top diagram shows magnetic field strength with a color scale in units of Tesla on the y-z plane. The red box outlines show the boundaries of the magnet. The bottom diagram shows the magnetic field modulus in Tesla along the z-axis from z=±8000 mm. The magnet spans z=± 1500 mm. The plots were constructed with 600 x 600 resolution in the OPERA Post-Processor.

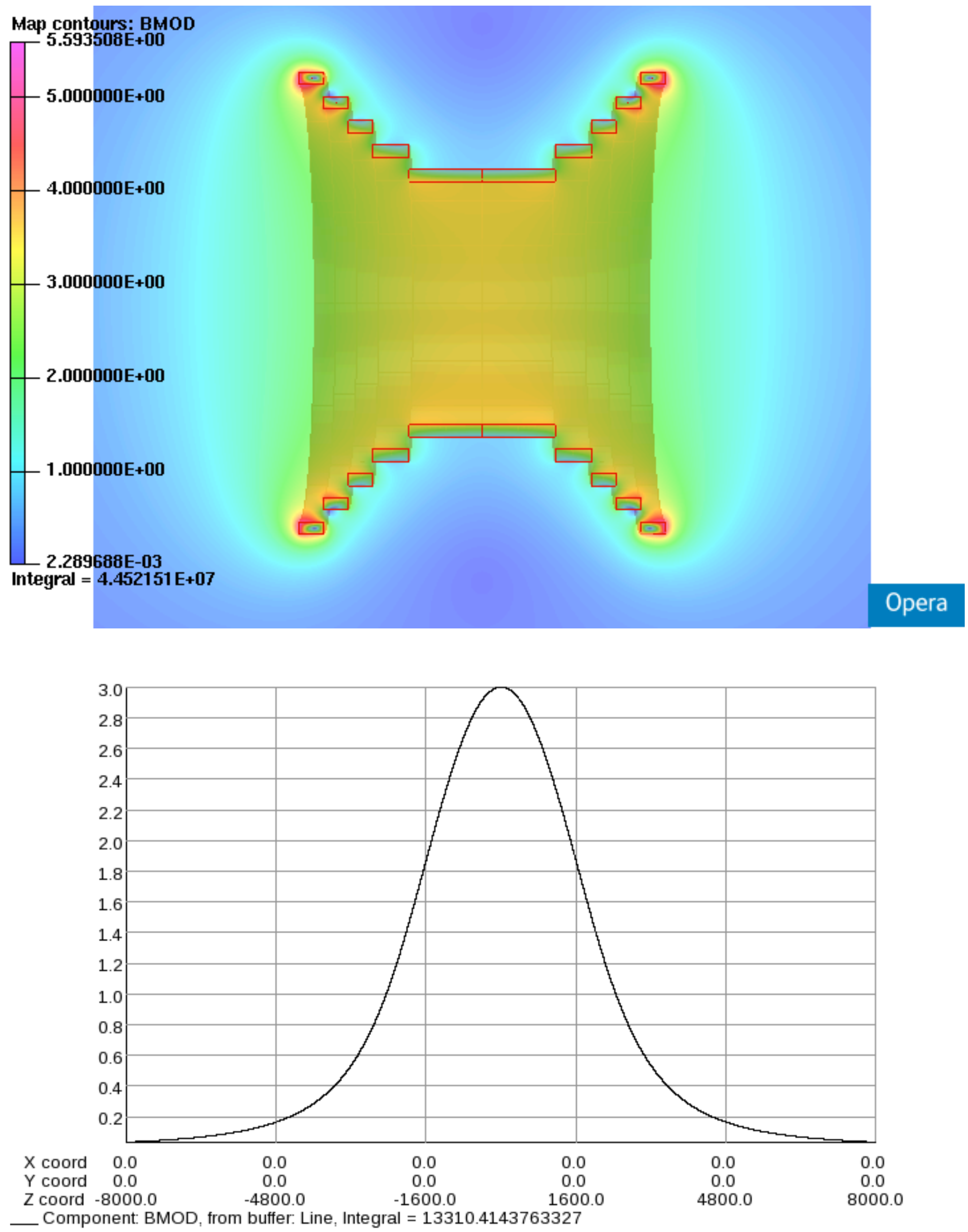


Fig. 5G – Magnetic field modulus mapping for the StrobS-B design. The central field strength (x=0, y=0, z = 0) is 3.001 T. The top diagram shows magnetic field strength with a color scale in units of Tesla on the y-z plane. The red box outlines show the boundaries of the magnet. The bottom diagram shows the magnetic field modulus in Tesla along the z-axis from z=±8000 mm. The magnet spans z=± 1500 mm. The plots were constructed with 600 x 600 resolution in the OPERA Post-Processor.

Conclusion

Our studies to date find the MRS-B1 design to be the best candidate for the eRHIC detector magnet. The design still needs to be optimized for momentum resolution and integration with the time projection chamber (TPC). Since we are yet to determine the effects of adding iron shielding (yokes) to our design, future design optimization will be done using the OPERA 2D modeler before building full-scale models in OPERA 3D. Future iron yoke additions will allow for lower current densities in magnet components. The replacement of some magnets with larger iron elements may also prove effective, especially in the case of increasing radial field components. At the time of writing our detector simulations are done using the MRS-B1's geometry and magnetic field maps.

Appendix - `.cond` files for eRHIC magnet designs and `.comi` files for "set-units"

Conductor Multiple Ring Solenoid MRS-A

```
CONDUCTOR
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 90.0 -90.0
1000.0 1000.0 1000.0 1200.0
1100.0 1200.0 1100.0 1000.0
0.0 0.0 0.0 0.0
34.0 0 'p5'
1 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 90.0 -90.0
1000.0 800.0 1000.0 1000.0
1100.0 1000.0 1100.0 800.0
0.0 0.0 0.0 0.0
33.0 0 'p4'
1 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 90.0 -90.0
1000.0 600.0 1000.0 800.0
1100.0 800.0 1100.0 600.0
0.0 0.0 0.0 0.0
33.0 0 'p3'
1 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 90.0 -90.0
1000.0 300.0 1000.0 600.0
1100.0 600.0 1100.0 300.0
0.0 0.0 0.0 0.0
32.0 0 'p2'
1 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 90.0 -90.0
1000.0 0.0 1000.0 300.0
1100.0 300.0 1100.0 0.0
0.0 0.0 0.0 0.0
30.1 0 'p1'
1 0 0
0.0
QUIT
```

Conductor Multiple Ring Solenoid MRS-B

```
CONDUCTOR
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 90.0 -90.0
1000.0 1000.0 1000.0 1200.0
1100.0 1200.0 1100.0 1000.0
0.0 0.0 0.0 0.0
90.0 0 'p5'
1 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 90.0 -90.0
1000.0 800.0 1000.0 1000.0
1100.0 1000.0 1100.0 800.0
0.0 0.0 0.0 0.0
50.0 0 'p4'
1 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 90.0 -90.0
1000.0 600.0 1000.0 800.0
1100.0 800.0 1100.0 600.0
0.0 0.0 0.0 0.0
25.0 0 'p3'
1 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 90.0 -90.0
1000.0 300.0 1000.0 600.0
1100.0 600.0 1100.0 300.0
0.0 0.0 0.0 0.0
12.5 0 'p2'
1 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 90.0 -90.0
1000.0 0.0 1000.0 300.0
1100.0 300.0 1100.0 0.0
0.0 0.0 0.0 0.0
6.25 0 'p1'
1 0 0
0.0
QUIT
```

Conductor Multiple Ring Solenoid MRS-B1

```
CONDUCTOR
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 90.0 -90.0
1000.0 1000.0 1000.0 1200.0
1100.0 1200.0 1100.0 1000.0
0.0 0.0 0.0 0.0
85.0 0 'P5'
1 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 90.0 -90.0
1000.0 800.0 1000.0 1000.0
1100.0 1000.0 1100.0 800.0
0.0 0.0 0.0 0.0
50.0 0 'P4'
1 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 90.0 -90.0
1000.0 600.0 1000.0 800.0
1100.0 800.0 1100.0 600.0
0.0 0.0 0.0 0.0
40.0 0 'P3'
1 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 90.0 -90.0
1000.0 300.0 1000.0 600.0
1100.0 600.0 1100.0 300.0
0.0 0.0 0.0 0.0
30.0 0 'P2'
1 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 90.0 -90.0
1000.0 0.0 1000.0 300.0
1100.0 300.0 1100.0 0.0
0.0 0.0 0.0 0.0
12.08 0 'P1'
1 0 0
0.0
QUIT
```

Conductor Simple Solenoid SS

```
CONDUCTOR
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 90.0 -90.0
1000.0 -1200.0 1000.0 1200.0
1100.0 1200.0 1100.0 -1200.0
0.0 0.0 0.0 0.0
31.73 0 'Default drive'
0 0 0
0.0
QUIT
```

Conductor Dipole-Solenoid DS

```
CONDUCTOR
DEFINE GSOLENOID
0.0 0.0 0.0 90.0 90.0 -90.0
0.0 0.0 0.0
0.0 0.0 0.0
1000.0 105.0 1000.0 350.0
1100.0 350.0 1100.0 105.0
0.0 0.0 0.0 0.0
40.0 0 'S2'
0 0 1
0.0
DEFINE HELIX
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 1205.0
0.0 0.0 0.0
100.0 175.0
450.0 450.0
1000.0 75.0
7.0 49.0
-30.0 0 'D'
1 0 1
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 90.0 90.0 -90.0
0.0 0.0 0.0
0.0 0.0 0.0
1000.0 350.0 1000.0 600.0
1100.0 600.0 1100.0 350.0
0.0 0.0 0.0 0.0
50.0 0 'S3'
0 0 1
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 90.0 90.0 -90.0
0.0 0.0 0.0
0.0 0.0 0.0
1000.0 600.0 1000.0 700.0
1100.0 700.0 1100.0 600.0
0.0 0.0 0.0 0.0
60.0 0 'S4'
0 0 1
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 90.0 90.0 -90.0
0.0 0.0 0.0
0.0 0.0 0.0
1000.0 0.0 1000.0 90.0
1100.0 90.0 1100.0 0.0
0.0 0.0 0.0 0.0
31.6 0 'S1'
0 0 1
0.0
QUIT
```

Conductor Dipole-Wrapped Solenoid DWS

```
CONDUCTOR
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 90.0 -90.0
1000.0 1000.0 1000.0 1200.0
1100.0 1200.0 1100.0 1000.0
0.0 0.0 0.0 0.0
80.0 0 'P5'
1 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 90.0 -90.0
1000.0 800.0 1000.0 1000.0
1100.0 1000.0 1100.0 800.0
0.0 0.0 0.0 0.0
50.0 0 'P4'
1 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 90.0 -90.0
1000.0 600.0 1000.0 800.0
1100.0 800.0 1100.0 600.0
0.0 0.0 0.0 0.0
40.0 0 'P3'
1 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 90.0 -90.0
1000.0 300.0 1000.0 600.0
1100.0 600.0 1100.0 300.0
0.0 0.0 0.0 0.0
30.0 0 'P2'
1 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 90.0 -90.0
1000.0 0.0 1000.0 300.0
1100.0 300.0 1100.0 0.0
0.0 0.0 0.0 0.0
19.15 0 'P1'
1 0 0
0.0
DEFINE HELIX
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 -600.0
0.0 0.0 0.0
100.0 175.0
550.0 550.0
1100.0 75.0
7.0 49.0
-25.0 0 'D'
1 0 -1
0.0
QUIT
```

Conductor Coaxial Ring System CoRiS-A

```
CONDUCTOR
DEFINE GSOLENOID
0.0 0.0 0.0 -90.0 90.0 90.0
0.0 0.0 0.0
0.0 0.0 0.0
1600.0 -600.0 1600.0 600.0
1500.0 600.0 1500.0 -600.0
0.0 0.0 0.0 0.0
20.74 0 'INNERSOL'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 -90.0 90.0
2690.0 -1610.0 2690.0 1610.0
2760.0 1610.0 2760.0 -1610.0
0.0 0.0 0.0 0.0
14.5 0 'OUTERSOL'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 90.0 90.0 -90.0
0.0 0.0 0.0
0.0 0.0 0.0
1480.0 592.68 1480.0 1231.18
1620.0 1231.18 1620.0 592.68
0.0 0.0 0.0 0.0
62.3 0 'H-Z'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 2303.86 90.0 90.0 -90.0
0.0 0.0 0.0
0.0 0.0 0.0
1480.0 1072.68 1480.0 1711.18
1620.0 1711.18 1620.0 1072.68
0.0 0.0 0.0 0.0
62.3 0 'H+Z'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
```

```
0.0 0.0 0.0
90.0 -90.0 90.0
2480.0 2010.0 2480.0 2044.9
2760.0 2044.9 2760.0 2010.0
0.0 0.0 0.0 0.0
18.0 0 'R3'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 -4054.9
90.0 -90.0 90.0
2480.0 2010.0 2480.0 2044.9
2760.0 2044.9 2760.0 2010.0
0.0 0.0 0.0 0.0
18.0 0 'R3'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 -90.0 90.0
1990.0 2010.0 1990.0 2044.9
2270.0 2044.9 2270.0 2010.0
0.0 0.0 0.0 0.0
37.0 0 'R2'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 -90.0 90.0
1500.0 2010.0 1500.0 2044.9
1780.0 2044.9 1780.0 2010.0
0.0 0.0 0.0 0.0
34.0 0 'R1'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 -4054.9
90.0 -90.0 90.0
1990.0 2010.0 1990.0 2044.9
2270.0 2044.9 2270.0 2010.0
0.0 0.0 0.0 0.0
37.0 0 'R2'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 -4054.9
90.0 -90.0 90.0
1500.0 2010.0 1500.0 2044.9
1780.0 2044.9 1780.0 2010.0
0.0 0.0 0.0 0.0
34.0 0 'R1'
0 0 0
0.0
QUIT
```

Conductor Coaxial Ring System CoRiS-B

```
CONDUCTOR
DEFINE GSOLENOID
0.0 0.0 0.0 -90.0 90.0 90.0
0.0 0.0 0.0
0.0 0.0 0.0
1100.0 -600.0 1100.0 600.0
1000.0 600.0 1000.0 -600.0
0.0 0.0 0.0 0.0
26.5 0 'INNERSOL'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 -90.0 90.0
2690.0 -1610.0 2690.0 1610.0
2760.0 1610.0 2760.0 -1610.0
0.0 0.0 0.0 0.0
7.0 0 'OUTERSOL'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 90.0 90.0 -90.0
0.0 0.0 0.0
0.0 0.0 0.0
980.0 592.68 980.0 1231.18
1120.0 1231.18 1120.0 592.68
0.0 0.0 0.0 0.0
39.0 0 'H-Z'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 2303.86 90.0 90.0 -90.0
0.0 0.0 0.0
0.0 0.0 0.0
980.0 1072.68 980.0 1711.18
1120.0 1711.18 1120.0 1072.68
0.0 0.0 0.0 0.0
39.0 0 'H+Z'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 -90.0 90.0
2480.0 2010.0 2480.0 2044.9
2760.0 2044.9 2760.0 2010.0
0.0 0.0 0.0 0.0
18.0 0 'R3'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 -4054.9
90.0 -90.0 90.0
2480.0 2010.0 2480.0 2044.9
2760.0 2044.9 2760.0 2010.0
0.0 0.0 0.0 0.0
18.0 0 'R3'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 -90.0 90.0
1990.0 2010.0 1990.0 2044.9
2270.0 2044.9 2270.0 2010.0
0.0 0.0 0.0 0.0
37.0 0 'R2'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 -90.0 90.0
1500.0 2010.0 1500.0 2044.9
1780.0 2044.9 1780.0 2010.0
0.0 0.0 0.0 0.0
34.0 0 'R1'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 -4054.9
90.0 -90.0 90.0
1990.0 2010.0 1990.0 2044.9
2270.0 2044.9 2270.0 2010.0
0.0 0.0 0.0 0.0
37.0 0 'R2'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 -4054.9
90.0 -90.0 90.0
1500.0 2010.0 1500.0 2044.9
1780.0 2044.9 1780.0 2010.0
0.0 0.0 0.0 0.0
34.0 0 'R1'
0 0 0
0.0
QUIT
```

Conductor Strobili Solenoid StrobS-A

```
CONDUCTOR
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 -300.0
90.0 90.0 -90.0
1200.0 1000.0 1200.0 1200.0
1300.0 1200.0 1300.0 1000.0
0.0 0.0 0.0 0.0
90.0 0 'P5'
1 0 0
0.0
DEFINE GSOLENOID
```

0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 -300.0
90.0 90.0 -90.0
1150.0 800.0 1150.0 1000.0
1250.0 1000.0 1250.0 800.0
0.0 0.0 0.0 0.0
50.0 0 'P4'
1 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 -300.0
90.0 90.0 -90.0
1100.0 600.0 1100.0 800.0
1200.0 800.0 1200.0 600.0
0.0 0.0 0.0 0.0
40.0 0 'P3'
1 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 -300.0
90.0 90.0 -90.0
1050.0 300.0 1050.0 600.0
1150.0 600.0 1150.0 300.0
0.0 0.0 0.0 0.0
30.5 0 'P2'
1 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 90.0 -90.0
1000.0 0.0 1000.0 600.0
1100.0 600.0 1100.0 0.0
0.0 0.0 0.0 0.0
18.06 0 'P1'
1 0 0
0.0
QUIT

Conductor Strobili Solenoid StrobS-B

CONDUCTOR
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 -300.0
90.0 90.0 -90.0
1800.0 1000.0 1800.0 1200.0
1900.0 1200.0 1900.0 1000.0
0.0 0.0 0.0 0.0
100.0 0 'p5'
1 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 -300.0
90.0 90.0 -90.0
1600.0 800.0 1600.0 1000.0
1700.0 1000.0 1700.0 800.0
0.0 0.0 0.0 0.0
50.0 0 'p4'
1 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 -300.0
90.0 90.0 -90.0
1400.0 600.0 1400.0 800.0
1500.0 800.0 1500.0 600.0
0.0 0.0 0.0 0.0
30.0 0 'p3'
1 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 -300.0
90.0 90.0 -90.0
1200.0 300.0 1200.0 600.0
1300.0 600.0 1300.0 300.0
0.0 0.0 0.0 0.0
21.0 0 'p2'
1 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 90.0 -90.0
1000.0 0.0 1000.0 600.0
1100.0 600.0 1100.0 0.0
0.0 0.0 0.0 0.0
19.53 0 'p1'
1 0 0
0.0
QUIT

Conductor Miniature Fourth Concept Detector mFCD

CONDUCTOR
DEFINE GSOLENOID
0.0 0.0 0.0 90.0 90.0 -90.0
0.0 0.0 0.0
0.0 0.0 0.0
815.2 -1050.0 815.2 1050.0
853.2 1050.0 853.2 -1050.0
0.0 0.0 0.0 0.0
103.0 0 'innerSolenoid'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 -90.0 90.0
1461.9 -1610.0 1461.9 1610.0
1500.0 1610.0 1500.0 -1610.0
0.0 0.0 0.0 0.0
28.0 0 'outerSol'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 90.0 90.0 -90.0
0.0 0.0 0.0
0.0 0.0 0.0
801.6 1072.68 801.6 1231.81
853.2 1231.18 853.2 1072.68
0.0 0.0 0.0 0.0
250.0 0 'innerSolHelmholtz'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 2303.86 90.0 90.0 -90.0
0.0 0.0 0.0
0.0 0.0 0.0
801.6 1072.68 801.6 1231.81
853.2 1231.18 853.2 1072.68
0.0 0.0 0.0 0.0
250.0 0 'innerSolHelmholtz'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 -90.0 90.0
1347.8 2010.0 1347.8 2044.9
1500.0 2044.9 1500.0 2010.0
0.0 0.0 0.0 0.0
11.0 0 'ring6'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 -4054.9
90.0 -90.0 90.0
1347.8 2010.0 1347.8 2044.9
1500.0 2044.9 1500.0 2010.0
0.0 0.0 0.0 0.0
11.0 0 'ring6'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 -90.0 90.0
1081.51 2010.0 1081.51 2044.9
1233.69 2044.9 1233.69 2010.0
0.0 0.0 0.0 0.0
12.0 0 'ring5'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 -90.0 90.0
815.21 2010.0 815.21 2044.9
972.82 2044.9 972.82 2010.0
0.0 0.0 0.0 0.0
11.0 0 'ring4'
0 0 0

```
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 -90.0 90.0
548.91 2010.0 548.91 2044.9
701.08 2044.9 701.08 2010.0
0.0 0.0 0.0 0.0
14.0 0 'ring3'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 -90.0 90.0
282.6 2010.0 282.6 2044.9
434.78 2044.9 434.78 2010.0
0.0 0.0 0.0 0.0
14.0 0 'ring2'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0
90.0 -90.0 90.0
114.13 2010.0 114.13 2044.9
209.23 2044.9 209.23 2010.0
0.0 0.0 0.0 0.0
7.0 0 'ring1'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 -4054.9
90.0 -90.0 90.0
1081.51 2010.0 1081.51 2044.9
1233.69 2044.9 1233.69 2010.0
0.0 0.0 0.0 0.0
12.0 0 'ring5'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 -4054.9
90.0 -90.0 90.0
815.21 2010.0 815.21 2044.9
972.82 2044.9 972.82 2010.0
0.0 0.0 0.0 0.0
11.0 0 'ring4'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 -4054.9
90.0 -90.0 90.0
548.91 2010.0 548.91 2044.9
701.08 2044.9 701.08 2010.0
0.0 0.0 0.0 0.0
14.0 0 'ring3'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 -4054.9
90.0 -90.0 90.0
282.6 2010.0 282.6 2044.9
434.78 2044.9 434.78 2010.0
0.0 0.0 0.0 0.0
14.0 0 'ring2'
0 0 0
0.0
DEFINE GSOLENOID
0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 -4054.9
90.0 -90.0 90.0
114.13 2010.0 114.13 2044.9
209.23 2044.9 209.23 2010.0
0.0 0.0 0.0 0.0
7.0 0 'ring1'
0 0 0
0.0
QUIT
```

OPERA Post-Processor "set-units" File

```
UNITS LENG=MM FLUX=TESLA
FIEL=AM SCAL=AMP VECT=WBM
DISP=CM2 ELEC=VM COND=SM
CURD=AMM2 POWE=WATT
FORC=NEWTON ENER=JOULE
MASS=KG
```